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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

STATISTICAL DIAGNOSTIC MODELING
OF MARINE FOG
USING MODEL OUTPUT PARAMETERS

by

Brian Lee Van Orman

June 1977

Thesis Advisor: R. J. Renard

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-- the most significant predictor parameter.

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Statistical Diagnostic Modeling of Marine Fog Using Model Output Parameters

by

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Diagnostic model output parameters, provided by the Fleet Numerical Weather Central, Monterey, California (FNWC), and the marine fog frequency climatology developed at the Naval Postgraduate School, Monterey, California, are statistically processed in context with marine surface synoptic ship reports for the purpose of developing a linear regression scheme for modeling the distribution of marine fog. The study area encompasses a large section of the North Pacific Ocean (from 30-60N). The time period involves 0000 GMT, 1-30 July 1976. The predictand is a fog parameter developed from a quantitative categorization of each of the 4481 synoptic observations according to reported present and past weather, low-cloud type, and visibility codes. The 38 model output and climatological predictor parameters are interpolated to each of the ship observation positions and the resultant data file is used for the derivation of the regression equations. The diagnostic capabilities of the regression equations, along with other existent approaches, are analyzed through the use of three verification scoring systems--Heidke Skill, Threat, and the Panofsky-Brier Probability scores. Improvement over climatology and FNWC's operational fog probability program (FTER, applied at analysis time) is demonstrated. Selective mappings of the regression equation outputs and categorized observations are intercompared with the sea-level pressure analysis; FTER; and the most significant predictor parameter in the regression equations, evaporative heat flux.

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I. INTRODUCTION AND BACKGROUND

Marine fog continues to be a threat to safe nautical and low-level aviation activities, civilian and military. Wheeler and Leipper (1974) documented various monetary and human losses associated with United States Navy operations in poor visibilities due solely to fog. An accurate analysis of marine fog, and its associated increases in forecasting accuracy, should help decrease these losses as well as enhance the specifications of low-level cloud inputs to the various planetary boundary layer models in the environmental sciences community.

Research on marine fog by the Departments of Meteorology and Oceanography at the Naval Postgraduate School (NPS) has concentrated on the climatology and the diagnosis of this phenomenon from observational data (Renard, Englebretson, and Daughenbaugh, 1975; Renard, 1976). A recent effort (Ihli and Renard, 1977) attempted to utilize satellite data in the diagnosis of marine fog regimes. The results indicate that the approach has potential, but more data are needed for further testing. In the realm of forecasting marine fog, an earlier study (Nelson, 1972) attempted an approach similar to the Model Output Statistics (MOS) method developed by the National Weather Service (NWS) (Glahn and Lowry, 1972). Nelson correlated visibility at sea over the North Atlantic Ocean to locally observed parameter values and developed

regression equations using the "perfect prognostic" approach. Out of the 20 or so parameters tested, wind speed, relative moisture content, and parameters associated with evaporation showed the highest correlations with visibility. He then tried to forecast visibility using, as predictors, grid point output values of these parameters from the operational models at the United States Navy Fleet Numerical Weather Central, Monterey, California (FNWC). The results showed little skill in the forecast mode.

Only FNWC is presently producing fog forecasts on a hemispheric basis through their statistical probabilistic product called FTER (see Appendix A). This product is the result of calculations based on a statistical processing of certain model output parameters related to fog occurrence (U. S. Naval Weather Service Command, 1975). FTER does not use any type of climatological parameter, partly due to the unavailability of accurate climatologies at the time of the development of the product. Only a limited evaluation of the FTER product has been accomplished to date (Renard, 1975b).

II. OBJECTIVES AND APPROACH

The primary objective of this study is to utilize the MOS concept in the development of a statistical equation (or set of equations) that would accurately specify the distribution of marine fog over an extensive oceanic area, such as the North Pacific Ocean. The secondary objective is to evaluate the skill of an existing operational scheme, FNWC's FTER product, and the NPS fog frequency climatology for the same region (Englebretson, 1974; Daughenbaugh, 1975; Willms, 1975). In essence, this is an "imperfect diagnostic" approach developed in part from numerically analyzed/predicted atmospheric and oceanographic parameters, similar to the MOS concept.

The approach used in pursuit of the primary objective involved three steps: a) the classification of each synoptic observation in the data base (described in Section IV) by cloud, weather, and visibility reported (predictand); b) the interpolation of model output grid-point parameters (and other parameters derived therefrom) and a climatological parameter (predictors) to the observation points; and c) the search for statistical relations between these predictors and the predictand. The immediate goal was to find one or more multiple, linear regression equations that would be significantly more skillful than either the NPS climatology or the FNWC FTER product in describing the actual distribution of fog at analysis time.

III. DATA

A. AREA OF STUDY

The NPS climatological fog frequency study (Willms, 1975) was confined to the North Pacific Ocean. Since this was judged to be the most accurate climatology of fog occurrence to date, the same general area was chosen for this study. Further restrictions were dictated by the desire to avoid the influences on fog patterns by large land masses and the large-scale upwelling in the waters off of the western coastline of the United States. The area of study is displayed in Fig. 1 on a Mercator projection. The area is outlined using the boundary I,J points of the standard 63-by-63 grid used by FNWC. Note the resultant curvature of the grid lines when the grid is placed on a Mercator projection. Fig. 2 has the same area and outline displayed on a Polar Stereographic projection. The entire FNWC I,J grid, on a Polar Stereographic projection, is shown in Fig. 3 for reference.

B. TIME PERIOD FOR STUDY

The month of July, 1976 was chosen as the basic time period. The main reason for this selection is the high relative frequency of marine fog for this month, as displayed in the NPS climatology (Willms, 1975).

The 0000 GMT synoptic time was chosen as best since this time is local noon over the international dateline (180 degrees) with daylight hours occurring over all of the area of

study. This factor should give maximum relative accuracy of observations by the transient ship observers (Nelson, 1972).

Other aspects involved in using only 0000 GMT data are persistence and diurnal variations. It is widely held that diurnal variations of meteorological phenomena in oceanic regions are minimal. In any case, the use of one synoptic time will eliminate any diurnal effect.

Panofsky and Brier (1968) suggest that, in order to eliminate persistence at stationary observation points, data from every third or fourth day be used in the dependent sample. Since the vast majority of the observations used for this study were from transient (non-stationary) ships, such persistence effects are considered negligible.

C. SYNOPTIC WEATHER REPORTS

FNWC provided all of the primary-time synoptic weather observations from their data archives. Duplicate reports and reports obviously in error were eliminated from the observations provided. In all, 4481 0000 GMT observations were obtained from the period 1-30 July 1976. Observations for 31 July 1976 were not available from FNWC.

While the majority of the observations came from transient ships, Ocean-Weather-Station P and 11 land (island or coastal) stations (see Fig. 1) were also included in the 4481 observations. The 11 land stations are listed in Appendix B, each with its station number, elevation, and location (latitude, longitude). The location of land station number 32618

was adjusted from its actual location (see Fig. 1) to just inside the study area.

D. MODEL OUTPUT PREDICTOR PARAMETERS

FNWC also provided all of the selected model output parameters (MOP's) for the time periods involved. These MOP's, their description and/or applicable remarks, and range of values (from histograms not shown) are listed in Appendix C. Some of the MOP's were chosen after consultation with Mr. Leo Clarke, Director of Research, FNWC, and others were chosen using the experience and advice of earlier studies (Schramm, 1966; Nelson, 1972; Grisham, 1973, Renard 1975a). The only desired MOP not available from the FNWC archives is a dew-point variable, but the EAIR (vapor pressure) parameter used in the study is derived from the dew point. The acronyms or abbreviations listed in Appendix C will be used as the variable names or symbols throughout the remainder of the report.

E. DERIVED PREDICTOR PARAMETERS

Other parameters used in the study were derived from the basic set of 21 MOP's provided by FNWC.[1] These are listed in Appendix D in the same manner as the basic MOP set is listed in Appendix C. As with the basic set, the acronyms and abbreviations listed are used in the remainder of the report.

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[1]Except Sensible Heat Flux (SHF) which was recovered from SHF = SEHF - EHF; it is listed in Appendix C.

F. CLIMATOLOGICAL FOG FREQUENCY PREDICTOR

The values of the NPS July climatological fog frequencies (Willms, 1975) used in the study were determined from interpolations to a 249-by-249 grid, which is about 1/4 of the FNWC I,J grid (Fig. 4). The resolution afforded by this fine spacing enabled the researcher to define all of the major features on the NPS July climatology charts. Such spacing is compatible with the original development of the fog frequencies, which were organized by one-degree-by-one-degree grid squares. Some subjective extensions to Willms' (1975) final isopleths were necessary in order to accommodate to the study area. These extensions are shown as the dot-dash isopleths in Fig. 4.

The overlay used for determining the climatological values at the grid points of the 249-by-249 grid was developed by computer plotting latitude, longitude values from a modified FNWC I,J-to-latitude/longitude program (See Appendix E). The other predictor variables were available for the standard 63-by-63 FNWC I,J grid-point locations. The abbreviation, CLIMO, used in the following portions of the text, stands for the NPS fog frequency climatology.

IV. FOGCAT PROGRAM

A. BACKGROUND

Until a methodology for using satellite data to identify marine fog regimes becomes operational, the main information sources for this purpose are synoptic ship reports and some island station reports. Previous researchers at the NPS used three elements of a ship's synoptic weather observations to categorize or differentiate between reports indicating fog ("foggers") and those indicating weather other than fog ("non-foggers"). The three elements used were present weather (ww), past weather (W), and visibility (VIS). See Tables I and II. While these elements certainly can be used to ascertain the occurrence/non-occurrence of fog, at least one additional element appears useful in determining the existence of fog regimes, namely, low cloud type (CL). See Table I.

Some of the combinations of ww, W, and CL used here as indicators of the occurrence of marine fog generally would not be considered valid in most verification schemes. However, this non-verification is primarily due to the existing rules in weather observing (U. S. Department of Commerce, 1969). These rules require the reporting of precipitation (ww more than 49, such as light drizzle or rain), even though a co-existing non-precipitation phenomenon (such as one of the modes of fog in the ww 40s group) may have more operational significance.

B. CATEGORIZATION PROGRAM

A scheme (FOGCAT; Fog Categorization) was devised to place each of the 4481 observations into one of the five major categories: Strong foggers (S), Foggers (F), Past/weak foggers (P), Maybe foggers (M), or Non-foggers (N). The scheme evaluates only the present weather (ww), past weather (W), and low cloud type (CL) codes for category placement. The synoptic visibility (VIS) code is not considered until the score assignment phase. A description of the FOGCAT scheme follows.

The 72 combinations of ww, W, and CL that are used in categorizing the observations are listed in Table IV, using the legend listed in Table III. The partitioning of the major categories into subcategories was done for three purposes, the least important of which is the collection of occurrence statistics for each combination. The listing order of the subcategories in Table IV is a subjective estimate of the degree of certainty of a given combination indicating the presence of operationally important fog at an observation point. The listing order was arranged with a view to both the skill of the observer and the precedence rules for reporting. In effect, it is assumed that the more and/or the denser the fog indicators reported by an observer (trained or untrained) in an observation, the more certain it is that the observation was taken in or near an existent fog regime. The second aspect of the listing order is that it provides a means of assigning a probabilistic score to each such

observation of ww, W, and CL; that is, a numerical value of the degree of certainty that fog was occurring.

The main problem encountered in devising FOGCAT involved the grouping of the various values of ww, W, and CL. The groupings used are listed in Table III, which is also the legend for Table IV. There are several major differences between the present (ww) and past (W) weather groupings therein and those used in the development of the NPS fog frequency climatology (Willms, 1975). The 50's (drizzle) and some of the 60's (rain) code values (see Table I) for ww are separated from the "any others" group. The ww code values of 10 (deep light fog), 28 (heavy fog in past hour), and 40 (light fog) are placed in the same group (10G). The code values of 20 (drizzle in past hour) and 24 (freezing drizzle in past hour) for ww are moved from the "any others" group to the one (11G) containing the values of 11 and 12 (shallow heavy fog). The elements in each of the latter two groupings do not necessarily have similarities in time or nature of fog but are related herein primarily due to a subjective consideration of their respective indicative qualities for the diagnosing of fog regimes.

The W code value of 5 (drizzle) is paired with 4 (fog) and this group (4,5 in Table III) is treated as a reliable fog indicator only when in combination with the ww groups of 41G (deep heavy fog) or 10G (the latter only for major category S). Otherwise, the W value of 5 is grouped (5G) with W values of 0-2 (sky coverage changes).

The low cloud (CL) type groupings are more straightforward. Values 5 (stratocumulus) and 7 (fractostratus of bad weather) are used to counter the possibility of an untrained observer substituting either of these for the more properly reported 6 (stratus or fractostratus). CL values reported as (/) indicate an obscuration. Of the 4481 observations used in the study, 919 have a CL of (/), and 466 of these are in the a2 subcategory.

1. <u>Major Category S</u>

The ww, W, and CL combinations comprising the strong fogger category generally have at least two strong fog indicators in combination. The strongest combination indicating fog is given by subcategory a1. However, over 50 per cent of the total S cases, 793, are categorized in the a2 subcategory. A relatively high number of all foggers were expected to fall into this subcategory because of the obscuring nature of fog and the results of Willms' (1975) study.

2. <u>Major Category F</u>

In general, there are at most two fog indicators in the combinations comprising this category. Placing subcategory d1 into the F, rather than S, category indicates the author's opinion that the CL value of B is not as certain a fog indicator as the CL value of 6 in subcategory c1. Subcategories d3 and d4, which are the first occurrences in the listing order of a 50G ww value, can be considered equivalent to a1 and a2 in a fog situation except that the precedence reporting rule prohibits reporting one of the 41G values.

But the total number of such cases is small and the effect on the final regression equation should also be minor.

3. Major Category P

The past/weak fogger category consists mainly of combinations which have a W value of 4 and no strong indication of fog at or within the past hour of observation time.

4. Major Category M

The "maybe" category represents the gray area of the scheme. Some of the reports that are placed in this category are likely to be in or near a fog regime, but are not verifiable as fog.

5. Major Category N

The non-fogger category was expected to include the majority of all the cases, and it did, as evidenced by 2604 observations or 56 per cent of the total.

C. SCORE ASSIGNMENT PHASE

In order to develop a multiple linear regression equation for specifying the probability of fog occurrence, it was necessary to assign a quasi-continuous numerical value to each unique combination of ww, W, and CL in the synoptic report. The nature of the FOGCAT table facilitates this value assignment, as well as the assignment of discrete, numerical or yes/no designations.

The continuous value assignments to the FOGCAT elements are illustrated in Table V. The letter portion of each subcategory symbol in Table IV was used to position the ww, W,

and CL combinations into the listing order of Table V. For example, the four subcategories, b1 thru b4, are combined into "b". This grouping of the four combinations that comprise subcategories b1 thru b4 effectively gives each of these four combinations the same degree of certainty.

The subcategory letter is paired with the visibility (VIS) value of each observation and a corresponding Base Score is determined. For example, an observation that has a VIS value of 92, and which receives a subcategory placement of k1 or k2, would be assigned a Base Score of 360. As such, Table V was used as a decision logic table.

It can be seen that a particular Base Score is assigned to many unique combinations of observed values of ww, W, CL, and VIS. For example, the Base Score of 260 can be assigned to any of 15 such combinations (five subcategories times the three visibility groups). The non-usage of the Base Scores of 160 and 180 makes a distinct gap or buffer zone in the continuous value range between those scores assigned to non-foggers and the ones assigned to observations with any possibility of being a fogger.

The assigned Base Score was then scaled by dividing it by 5.8. This yielded the Fog Score, which was used as the predictand (dependent variable) during the regression phase. The Fog Score values (rounded) are listed next to the Base Score values in Table V.

D. FURTHER REMARKS ON FOGCAT

Other researchers would undoubtedly use different placements of the combinations of ww, W, and CL in the listing order of Table IV. Still others might suggest that the CL values could be used only if the sky cover code (N) value is co-evaluated. The Base Score assignment procedure could be kept "pure" by having a Base Score for each of the 72 combinations listed in Table IV and restructured in Table V. The Base Score range could then be 0-770 (intervals of 10 rather than 20), and/or the intervals could be variable so that Base Scores for foggers are close together but those for non-foggers would be farther apart (given consecutively listed subcategories). But, as a means to accomplish what is basically a feasibility study, FOGCAT is felt to be a "reasonable" scheme.

Support for Nelson's (1972) general comments on the accuracy of the transient ship synoptic observations is shown in the counts listed in Table IV. According to the observing rules (U. S. Department of Commerce, 1969), those observations having present weather values in the 40's should also have VIS values in the 90-93 range. Subcategory a2 ended up with a total case count of 466. By the rules, all 466 of these observations should have ended up being listed in the "Poor VIS" count for the a2 combination. Only 360 were so listed. It would have been possible to "bogus" in the proper visibility for those 106 faulty observations, but this was not attempted.

The number of observations in Table IV for the a2 subcategory and the N major category have already been discussed. At least one other such count deserves mention, namely, the count of 313 observations for subcategory n1. The meaning of this unexpected high count is unclear, but the CL value of 6 suggests these observations may have been taken at or near fog regimes. A shift in the position in the listing order of Table IV for this subcategory should definitely have a noticeable effect on the resultant regression equations.

V. PREDICTOR INTERPOLATION

The interpolation scheme chosen to provide values of the 38 predictors (21 MOP's, 16 derived MOP's, and CLIMO) to the observation points is a natural bicubic spline curvilinear interpolation scheme, locally called SPLIN. The locally developed computer program is available at the NPS W. R. Church Computer Center. The scheme can handle large arrays (up to 300-by-300). But for time considerations, it was decided to limit the array to a 4-by-4 matrix for each interpolation performed.

In order to use any interpolation scheme, it is necessary to be able to find the observation points in the same frame of reference as the predictors. This was accomplished through the latitude/longitude-to-I,J-coordinates conversion formulae described in Appendix F. The resultant I,J coordinates (63-by-63 grid) for a given observation point were used to generate the coordinates required with respect to the 249-by-249 grid used to derive the CLIMO values.

The nature of the interpolation scheme, which is essentially a cubic curve fitting process, is such that errors can be introduced when the majority of the 4-by-4 array values are very similar to one another in sign and magnitude. These errors, and their possible effects, will be discussed later.

VI. REGRESSION SCHEME

A. BACKGROUND

A stepwise multiple linear regression program, called BMDP2R (*University of California*, 1973), is available at the NPS W. R. Church Computer Center, and was chosen as the means to derive a marine fog diagnostic equation. BMDP2R computes a sequence of multiple linear equations in a stepwise manner. At each step one variable is added to or deleted from the previous step's equation as dependent on the F-to-enter and F-to-remove criteria. Generally, the variable entered into the equation, in any given step, is the one which makes the greatest addition to the amount of predictand variance explained (ΔR^2).

The BMDP2R program permits the specification as to whether or not the y-intercept (YI) is to be treated as a variable or predictor. It is also possible to specify the tolerance level, which is a factor controlling the possible linear interdependencies or correlations between the various predictor variables. This tolerance specification is used by the program to inhibit the entering of a variable which has a high correlation to another previously entered variable. A case in point may be seen in Table VI, which lists correlations of all predictors to Fog Score along with the ranges of the variables. It can be seen that the correlations between the Fog Score predictand and both the EHF and SEHF predictors are

similar in magnitude and sign. The first regression equation obtained (see Table VII) used EHF as a predictor, but not SEHF. The correlation coefficient between EHF and SEHF is 0.94 for the data used, which shows the high, and expected interdependence between these two predictor variables, and thence, why the tolerance control will tend to keep SEHF out of the equation. The other correlations between the predictor variables are not shown.

The approach taken in this study was to allow the treatment of the y-intercept (YI) as a variable and to use the BMDP2R program's default values of 4.0, 3.9, and 0.01 as the values for the minimum acceptable F-to-enter, maximum acceptable F-to-remove, and the minimum acceptable tolerance criteria, respectively.

B. OUTPUT RESULTS

1. Correlations

The simple correlation coefficients (cc), between Fog Score and the 38 predictor variables, for the entire set of 4481 observations are listed in Table VI. The groupings of the variables are for easier comparison between variables with similar characteristics, such as temperature, and/or model source. See Appendices C and D for model sources.

The largest absolute cc value is the one listed for the EHF predictor. All of the other heat-flux type variables, except SOLARAD, also have relatively high cc values.

Also worth noting are the ccs for the FTR and CLIMO predictor variables. This leads to the expectation

that the results in Section VII (Verification Scoring) would show that FTER possesses little, if any, skill over CLIMO in the diagnosis of the July 1976 marine fog regimes.

2. Regression Equations

The FTER and DDWW variables were removed from the BMDP2R program's use list before the generation of the first set of regression equations was developed. FTER was removed because it is the existent predictor over which improvement is desired. DDWW was removed because it is a cyclic (0 = 360 degrees) variable. Cycle variables are ill-conditioned for use in regression programs. Other cyclic variables, which were not recognized as such until late in the study, are PDW and SDW. Their inclusion as variables in some of the resultant equations may be undesirable, but time restrictions prohibited regeneration of the equations without them.

The set of equations generated by BMDP2R for the whole study area (4481 cases) is listed in Table VII. They are listed in their respective stepwise order along with the variable regression coefficients, YI values, explanations of variance (R^2), and the increase in R^2 at the end of each step. A discussion of Eq. (9.9) will occur later in the verification section.

It is readily seen that the EHF variable, in conjunction with YI, is the most significant predictor of the Fog Score. Since SEHF and the rest of the heat flux parameters were excluded by the tolerance specification, a separate run was made with EHF removed from the program's use list, with

the purpose of determining whether SEHF would be entered first in place of EHF. This was expected, because SEHF has the second largest cc magnitude. The results (not shown) upheld the expectations. SEHF did replace EHF as the first variable to enter.

Along with the EHF variable, only CLIMO, EAIR, and TSEA are significant variables in the explanation of the Fog Score variance. This significance is based on an R^2 increase of 0.005 rather than the widely held standard of 0.01. If 0.01 were used as the significance limiter, EHF would be the only such variable, along with the constant YI.

None of the variables listed for Eq. (9) were unexpected. All of them can be logically and physically associated with the occurrence of marine fog. The association of T925 and fog is rather difficult to understand. This correlation is probably primarily due to the meridional distributions of fog regimes and air temperatures, as is known to be the case with TSEA.

Two other equations generated for the whole area are listed in Table VIII. The final step equation and its respective coefficients are listed, as well as the ΔR^2 due to each variable entered, the final R^2, variables deleted (if any) and their associated ΔR^2 at entry and removal. Variables not given consideration (not in use list) during the regression are also listed.

The development of Eq. (9T) stems from a transformation of the Fog Score variable (predictand). This

transformation (T) takes the form of Fog Score = Fog Score - CLIMO. Effectively, this forces the regression coefficient of CLIMO to be one (1.0), as is reflected in Table VIII. Thus, CLIMO was not allowed entry into the equation as a predictor during the stepwise procedure. The final R^2 for Eq. (9T) indicates that this approach holds little promise for useful application.

The second equation listed in Table VIII is Eq. (9NC). In this experiment CLIMO was removed as a predictor variable. This regression result was run at the request of FNWC due to unavailability of acceptable fog frequency climatology for all oceans. The results, except for entry order, are similar to Eq. (9). The PDW variable is higher on the selection list than its counterpart in Eq. (9) and its significance is higher. In any case, the influence of this cyclic variable is minimal.

Two sub-area equations were also obtained. The whole area file was sorted and copied into two smaller files, one [for Eq. (39)] for those cases (1504 observations) south of 40N, and the other [for Eq. (40)] for all the other cases (2977 observations), namely, at or poleward of 40N. The final-step forms of these two equations are listed in Table IX. The final R^2 for Eq. (40) was the highest obtained, while that for Eq. (39) was the lowest, with the exception of Eq. (9T). This "poor" showing by Eq. (39) might be attributed to the low occurrence of fog in the southern zonal belt below 40N. There were only 107 foggers (major category S and F) in the 1504 observation reports in that area.

Two other runs made with BMDP2R are also worth mentioning. One run had FTER as the only predictor variable in the use list, the other run had CLIMO as such. The runs were made against the whole area data file. The final R^2 for the FTER run is 0.5092, and for the CLIMO run, 0.5391. This strengthened the expectation that FTER would possess little, if any, skill over CLIMO as a fog predictor.

VII. VERIFICATION SCORING

A. BACKGROUND

Two types of verification scores are used in the study to test the "skill" of different predictors in describing the distribution of the FOGCAT major category designators (S, F, P, M, N). The first type of scoring is used in judging the effectiveness in forecasting ("nowcasting" in this study) discrete (event, non-event) occurrences of a given phenomenon. The second type of scoring is used to judge the effectiveness of probabilities in estimating the occurrence of the event. In all, three scores are used in this study. The first two, Heidke Skill Score (HSS) and Threat Score (TS), are of the first type of scoring approach. The third score, Probability Score (PS), evaluates the probability of fog as assigned by Fog Score, FTER, or CLIMO, and is of the second type described above.

The exact formulae used for the three scores (HSS, TS, and PS) are given in Appendix G. The Heidke Skill Score has been used for quite some time in the meteorological community but may be falling into disfavor currently, while the Threat Score is currently in vogue with the National Weather Service. The Probability Score is appropriate to a predictor given in terms of a probability with a range of 0-100 per cent.

B. RESULTS

1. Heidke Skill and Threat Scores

Tables X through XIII show the various results for the HSS and TS calculations. The FOGCAT major categories of S and F were used as the criteria for classifying an observation as a "fogger". The cutoff or cut value for a predictor is considered to be that value at which the estimate of the event is changed from a "yes event" estimate to a "no event" estimate (or vice versa). Only those cut values listed for FTER and CLIMO were used, because of the results of an earlier study (Renard, 1975b). The cut values for the equations are those giving the best verification results.

Table X reflects the results hopefully expected at the beginning of the study, namely, Equation (9)'s relatively significant improvement over either FTER or CLIMO as a marine fog diagnostic tool. CLIMO and FTER are quite comparable in skill, which upholds the earlier expectation. Eq. (9T), which shows "poor" R^2 results, is comparable to Eq. (9) in HSS and TS results, as are Eqs. (9NC) and (9.9). The listing of the scores for Eqs. (1) through (8) shows the generally step-by-step increase in the scores. This listing complies with a suggestion by Panofsky and Brier (1968) to test each of the equations in the stepwise regression scheme.

Listed in Table XI are the number of observations per day as well as the associated skill scores for the three predictors FTER, CLIMO, and Eq. (9), using the best cutoff values from Table X for each of them. The day-by-day

comparison shows a good improvement of Eq.(9) over the capabilities of FTER and CLIMO in the diagnosing of the event. The day-by-day comparisons in Table XII for Threat Scores further highlights the merits of Eq. (9) in comparison to FTER and CLIMO.

The results listed in Table XIII for the two zonal belts again show relatively significant improvement by the regression equations over FTER and CLIMO. The equations are comparable within the respective areas. That is, Eq. (9) (whole area equation) exhibits about as much skill as the equations generated specifically for the sub-areas.

2. Probability Scores

These scores for the three predictor types are listed in Tables XIV and XV. CLIMO shows a slight improvement over FTER (the smaller the value, the better the skill) while Eqs. (9), (9T), and (9NC) show very little improvement over CLIMO. Eq. (9.9) shows the best improvement. This equation was obtained by changing the YI value of Eq. (9) with the express goal of optimizing the resultant PS. However, the optimization effect did not carry over to the HSS and TS results listed in Table X.

The zonal-belt PS results listed in Table XIV show that the equations have a slight improvement in the northern belt over FTER and CLIMO. But in the southern belt CLIMO has the best score. This is probably due to the preponderance of "good" weather (non-fogger) observations south of 40N.

The daily PS values listed in Table XV support the findings in Table XIV, namely, that Eq. (9) does not show much improvement over CLIMO and/or FTER. The daily performance of Eq. (9.9) (optimized) shows a far better than average improvement over Eq. (9), FTER, and CLIMO on a temporal frequency basis.

The relatively small improvement of Eq. (9) over CLIMO and FTER in the PS results, as compared to the TS and HSS results, can be examined more closely by using Table XVI. Eq. (9) does a better job of specifying the foggers in the higher probability classes than CLIMO or FTER while CLIMO and FTER perform better in indicating non-foggers in the lower probability classes. The results of the PS calculations indicate these two forecasting aspects yield comparable PS values for CLIMO, FTER, and the regression equations. The figures listed in Table XVI compare favorably to those of Renard (1975b) for July 1974 data.

Whenever a predictor probability value was negative, zero was substituted so as not to cause complications with the PS formula. (See Table XIV.) This adjustment was not necessary for the HSS and TS calculations.

VIII. COMMENTS

In section V it was indicated that the interpolation scheme might introduce errors into the data base. This error production can be readily seen by comparing the value ranges of the predictor parameters before and after the interpolation. The "before" values are listed in Appendices C and D, while the "after" values are listed in Table VI. The effect of this error introduction is clearly shown by the cases of below-zero value for the FTER variable listed in Table XIV. The FTER range has been expanded from 0.0 to -0.09 on the low end and from 1.00 to 1.02 on the high end. The values may not seem significant, but 1183 observations were assigned negative values of FTER by the interpolation process rather than the more desirable zero or small positive values. To check the extent of this effect, two additional Probability Score runs were made in which each of the 4481 values of FTER was modified. The results of these runs are the FTER +0.02 and FTER +0.05 entries in Table XIV. It can be seen that 891 of the 1183 observations received interpolated FTER values of 0.0 to -0.02, which is judged to be an acceptable deviation from zero.

Mappings of sea-level pressure, EHF, FTER, probabilities from Eq. (9), and verifying observations by FOGCAT are displayed for days 12 and 24 in Figures 5 through 14. The EHF charts are included since this model output parameter is

predominant in explaining a large amount of the variance of fog. Day 12 was chosen because the scores produced for FTER and Eq. (9) are about "average", considering all days studied, while the performances of these two predictors for day 24 are "well above average".

IX. CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this study was to utilize the Model Output Statistics approach in the development of a statistical regression equation that can accurately specify the distribution of marine fog. Through the interpretation, categorization, and statistical processing of various data elements, an equation was obtained whose variables are logically and/or physically related to fog (Table VII). The secondary objective, that of evaluating the skill of the different predictors (FTER, CLIMO, and the equations obtained) against a given data base, was fully achieved.

The methodology of using diagnostic model output parameters, rather than observational values, for describing the initial distribution of marine fog has tremendous potential. The equations obtained show significant increases in skill in performing this task in comparison to the use of climatology or the current FNWC fog forecasting product, FTER. FTER was shown to have no appreciable skill over the NPS fog frequency climatology (CLIMO) for the criteria used.

Regression Eq. (9), developed by using the whole area data file, proved to be as skillful in zonal band application as were the equations generated for the zonal bands. This suggests that the zonal band partitioning does not segregate dissimilar areas well enough with respect to fog occurrence.

The following recommendations are offered for both short range and long range continuations of this work:

(1) Process the July 1976 parameters and observations again, using one or more different interpolation schemes.

(2) Break up the area of study into a multiple number of sub-areas on both geographical/meteorological bases and derive regression equations for each area.

(3) Recover the long wave (LW) portion of the THF parameter and redo the July 1976 investigation including this parameter.

(4) Test the regression scheme in a forecast mode, using primitive equation prognostic model output parameters.

(5) Perform the same procedures, and modifications listed in these recommendations, on data from different months and/or synoptic times.

(6) Process the data bases using a discriminate analysis procedure.

(7) Analyze scatter diagrams from the data base using a non-linear approach.

(8) Plot the FOGCAT designations for each synoptic report each day and research the areas of fog generation, maintenance, and advection. Relate these fields to changes in the patterns of significant variables such as EHF.

(9) Experiment with changes to the FOGCAT structure and Fog Score assignment method or intervals.

(10) Use Eq. (9) or (9NC) on a test operational basis as soon as practicable, and test the skill against FTER.

(11) Introduce a fog persistence parameter into any regression scheme for prognostic probabilities. This parameter also may be useful for the diagnostic probability equations.

(12) Eliminate the advection terms from consideration during the regression runs and redo the July 1976 investigation. This would decrease the complexity of the parameters required for the "final" product.

APPENDIX A - Description of FNWC's Fog Probability Forecast Program (U. S. Naval Weather Service Command, 1975).

1. <u>Program Development</u>

The forecast for Advection Fog probability is based on a system of multi-parameter tests, where each parameter is weighted on the basis of test results. The weights of all parameters are summed, divided by 5, and normalized to give a value of zero to one, representing probability. 0.1 would be 10% probability; 0.9 would be 90%.

Advection Fog has five tests:

(1) When surface air temperatures are near $0^{o}C$, there is a high probability of fog. (Based on S. Petterssen) Weights favoring fog are assigned in the $\pm$ $5^{o}C$ range from $0^{o}C$.

(2) When condensation is taking place, there is usually an effective fog condition. This test is done by using evaporation calculations from moisture parameters. If evaporation is negative or zero, a certain weight is assigned to allow for the condensation factor.

(3) If the near surface relative humidity exceeds a certain critical value (> 95%), a high weight is assigned on fog probability.

(4) An air mass discriminant is applied. If the surface geostrophic wind is being advected toward warmer (or colder) surface conditions, the air mass would be

classified accordingly--as in the old k and w air-mass system. A warm air mass would call for a high weight. The weight assigned is based upon calculations of the air mass wind component normal to the isotherms.

(5) A weight is derived from application of a Fog Criterion. The criterion is based upon the change in dew point that occurs during the mixing of two air masses of dissimilar character. The resulting dew point depression in the mixed air is related to fog probability, which establishes a certain criterion value, a strong probability weight is assigned.

User activities receive the fog probability forecasts in the form of a field, where each grid point has a fog probability value.

2. <u>Program Input</u>

(1) Sea-surface temperature analysis.

(2) Surface air temperature analysis.

(3) Surface vapor pressure analysis.

(4) Sea-level pressure 6-hourly analysis.

(5) P.E. prognoses of the above parameters from 0-48 hours.

3. <u>Program Computation</u>

The various tests are calculated as described above for parameters at Tau's equal to 0, 6, 12 to 72 hours. The fog probability FTER is calculated for all land and sea points.

4. Program Limitations

The five-parameter test method is admittedly somewhat gross in character, but has enough built-in controls to insure a correct answer--given correct humidity values. The program gives excellent results in cases of broad-scale fog. The weakness of the program stems almost entirely from use of the large 63x63 grid. Local effects just cannot be accounted for, and fog is particularly susceptible to small-scale effects such as cold air drainage, small bodies of water, and man-made air pollution. Forecasters, in using the Advection Fog products, should always make allowances for known local effects.

APPENDIX B: Land Stations Used in Study (U. S. Air Force, 1972).

Station Number	Latitude	Longitude	Surface Elevation (ft)
32174	45.2 N	147.9 E	38
32186	46.2 N	150.5 E	73
32195	46.9 N	151.9 E	26
32207	48.3 N	153.3 E	55
32213	50.9 N	156.7 E	42
32215*	50.7 N	156.2 E	unknown
32217	50.0 N	155.4 E	11
32559	53.1 N	160.0 E	88
32594	51.5 N	156.5 E	6
32618	54.9 N**	166.2 E**	19
70454	51.9 N	176.7 W	14

* Station not listed in reference. Lat/long values listed are as given with each synoptic report furnished by FNWC.

** Location given slightly removed from actual location of 55.2 N latitude, 166.0 E longitude to accommodate study area.

APPENDIX C. Output Parameter Descriptions.

Source Model

Symbol	Name / Description	Mean*	Minimum*	Maximum*	Units
A.	**Analysis Parameters (FNWC's Mass Structure Model)**				
PS	Sea Level Pressure: Analysis of observed sea level parameter.	1017.2	981.2	1034.0	(mb)
TAIR	Surface Air Temperature. Analysis of observation-level air temperature.	17.9	3.5	30.3	(°C)
EAIR	Surface Vapor Pressure: Analysis of observation-level vapor pressure derived from the dew point.	18.1	3.0	38.4	(mb)
T925	925 mb Air Temperature: Analysis of 925 mb air temperature.	16.2	-4.4	26.4	(°C)
TSEA	Sea Surface Temperature: Once-daily analysis of observed sea-surface temperature.	16.6	4.1	29.0	(°C)
B.	**P.E. Parameters (FNWC's Primitive Equation Model)** (Kaitala, 1974)				
TX	Surface Air Temperature: Derived from surface air and potential temperatures, boundary layer depth, upper-level winds extrapolated to surface, air density, drag coefficient, gustiness factor, and empirical constants.	18.5	5.3	28.2	(°C)
EX	Surface Vapor Pressure: Derived from model's mixing ratio.	18.4	6.6	33.7	(mb)
SOLARAD	Solar Radiation: Calculated absorption of incoming short-wave (solar) radiation (positive downward) (H = depth unit).	46.5	25.9	88.4	(g·°C/cm²·H)
EHF	Evaporative Heat Flux: Derived using air density, drag coefficient, extrapolated winds, and mixing ratios.	5.5	-14.9	26.3	(g·°C/cm²·H)

APPENDIX C (continued)

SEHF	Sensible/Evaporative Heat Flux:	1.9	-39.7	27.9	(g·°C/ cm²·H)
	SEHF = Sensible Heat Flux (SHF) + EHF				
SHF	Sensible Heat Flux:	-5.6	-28.4	3.6	(g·°C/ cm²·H)
	Recovered from SHF = SEHF-EHF. Originally derived by FNWC using drag coefficient, extrapolated winds, surface air temperature, TX, density, and constants.				
THF	Total Heat Flux:	-37.6	-80.9	-9.0	(g·°C/ cm²·H)
	THF = SEHF - SOLARAD + LW, where LW is the heating due to long-wave (terrestrial) radiation.				

C. <u>Marine Wind Model (FNWC)</u>

VVWW	Marine Wind Speed:	13.3	0.0	74.8	(knots)
DDWW	Marine Wind Direction:	18.7	0.0	36.0	(degrees/ 10)
	Both variables derived from a dynamic balancing of surface wind and sea-level pressure.				

D. <u>Spectral Ocean Wave Model (S.O.W.M.)(FNWC)</u>

HW	Significant Wave Height:	4.4	0.0	22.1	(feet)
PPW	Primary Wave Period:	8.2	0.0	20.0	(sec)
PDW	Primary Wave Direction:	18.2	0.0	33.7	(degrees/ 10)
SPW	Secondary Wave Period:	5.6	0.0	25.0	(sec)
SDW	Secondary Wave Direction	11.5	0.0	33.7	(degrees/ 10)
WCP	Probability of White Caps:	0.3	0.0	7.0	(per cent)

APPENDIX C (continued)

E. Other Model Output Parameters (FNWC)

SSTA	Sea Surface Temperature Anomaly:	-0.6	-4.5	3.0	(°C)
	Calculated anomaly of sea-surface temperature from the mean of the day as interpolated from the monthly mean values.				
FTER	Probability of Fog:	0.1	0.0	1.0	(per cent)
	Forecast of advection fog probability.				

*These values are for the grid points in the rectangular area (Fig. 3) encompassing the area of study for 1-30 July 1976, including 0.0 for wave parameters over land points.

APPENDIX D: Derived Parameter Descriptions

Symbol	Name / Description	Mean*	Minimum*	Maximum*	Units
u	Zonal Wind Component	1.7	-20.9	28.9	(m/sec)
	u = -VVWW sin (DDWW · 10).				
v	Meridional Wind Component	1.3	-25.2	25.4	(m/sec)
	v = -VVWW cos (DDWW · 10).				
CAPU	I Directional Wind Component:	1.2	-24.8	20.5	(m/sec)
	CAPU = -u · sin(LNGA) - v · cos(LNGA), (Haltiner, 1971).				
CAPV	J Directional Wind Component:	-2.0	-35.1	18.7	(m/sec)
	CAPV = u · cos(LNGA) - v · sin(LNGA), (Haltiner, 1971). where LNGA = -10 -(I,J point longitude).**				
THETAX	Potential Temperature X:	290.1	277.5	300.7	(°K)
	Derived using PS, TX.				
THETAR	Potential Temperature R:	289.5	276.5	301.7	(°K)
	Derived using PS, TAIR.				
STABX	Stability X:	-0.06	-0.19	0.07	(°K/mb)
	Derived using [THETAX -(THETA of T925)]/(PS-925). Value greater than zero indicates absolute instability.				
STABR	Stability R:	-0.07	-0.25	0.12	(°K/mb)
	Derived using [THETAR -(THETA of T925)]/(PS-925). Same value effect as STABX.				
ASTDX	Air-Sea Temperature Difference X:	1.9	-3.4	11.8	(°C)
	ASTDX = TX - TSEA.				
ASTDR	Air-Sea Temperature Difference R:	1.3	-5.6	9.7	(°C)
	ASTDR = TAIR - TSEA.				
ADTSEA	Advection of TSEA:	0.04***	-0.79	0.95	(°C/ Hour)
	Formulae and notes below.				
ADTX	Advection of TX:	0.35***	-0.73	1.02	(°C/ Hour)
	Formulae and notes below.				

APPENDIX D (continued)

ADTAIR	Advection of TAIR: Formulae and notes below.	0.04***	-0.85	0.86	(°C/ Hour)
AASTDX	Advection of ASTDX: Formulae and notes below.	-0.00***	-0.69	0.78	(°C/ Hour)
AASTDR	Advection of ASTDR: Formulae and notes below.	0.00***	-1.02	0.64	(°C/ Hour)

*These values are for the grid points in the rectangular area (see Fig. 3) encompassing the area of study.

**I,J point longitude calculated using I,J-to-latitude/longitude conversion formulae described in Appendix E.

***Mean may be biased towards zero. Only values used in study were calculated. Grid points outside study area received zero.

Advection Formulae and Conditions:

For the advection of a quantity (R) the formula, $ADQ = -\bar{V}\cdot\nabla(Q)$, was used in the following finite difference form:

$$ADQ = -\frac{RMAP}{DM}[CAPU\cdot(Q_{I+1} - Q_{I-1})_J + CAPV\cdot(Q_{J+1} - Q_{J-1})_I],$$

where $RMAP = (1 + \sin(60))/(1 + \sin(\text{latitude}))$

and $DM = [(2)\cdot(6.37\cdot10^6)\cdot(1 + \sin(60))]/31.205$

(31.205 = grid mesh lengths, pole to equator, on FNWC's I,J grid).

In the temperature advection calculation for point C, using the five grid points illustrated below, one or two of the points, namely, A, B, D, or E, may be outside the study area. In the bogusing method suggested by Mr. Leo Clarke, FNWC, when a non-center point (e.g., point A) was judged to probably produce a land and/or dissimilar sea area influence on the resulting advection, the center point value (point C) was substituted for it. This "bogusing" is necessary to maintain a "purely" marine characteristic in the resultant parameter value.

The set of study area boundary grid points used for bogusing (and some double bogusing) are depicted in Fig. 2. The upper case letters denote the points whose values were used for the bogusing. The lower case letters mark the positions of the adjacent points being bogused. The only boundary point close enough to land to give concern is to the one near station number 32594 (south tip, Kamchatka Peninsula).

APPENDIX D (continued)

However, it was judged to be over the ocean after examining TX, TAIR, and TSEA values at this and adjacent land/ocean I,J-grid points.

	A	
.	I+1,J	.
B	C	D
I,J+1	I,J	I,J-1
	I	
.	I-1,J	.

APPENDIX E: Conversion of I,J grid coordinates to latitude/longitude positional values (FNWC Subroutine Library).

The following formulae were programmed in Fortran as a subroutine used by several different large programs developed for this study:

$$\text{LONGITUDE} = K - \arctan\,[(J-J_p)/(I-I_p)]$$

$$\text{LATITUDE} = \arcsin \frac{(\text{RED})^2 - (I-I_p)^2 - (J-J_p)^2}{(\text{RED})^2 + (I-I_p)^2 + (J+J_p)^2}$$

where: K = -10 or 170 depending on quadrant used in study. (-longitude means West longitude)

J_p = Pole position = 31*

I_p = Pole position = 31*

RED = Distance from pole to equator in grid mesh lengths = 31.205

*32 used on IBM 360/70 at NPS W. R. Church Computer Center.

APPENDIX F: Conversion of latitude/longitude position to I,J grid coordinates (FNWC Subroutine Library).

The following expressions were programmed for use during the interpolation phase of the study:

$$I = I_p + [RED \cdot (\frac{\cos \phi}{1 + \sin \phi}) \cdot \cos(-10+\lambda)]$$

$$J = J_p + [RED \cdot (\frac{\cos \phi}{1 + \sin \phi}) \cdot \sin(-10+\lambda)]$$

where ϕ = Latitude

λ = Longitude (negative = West)

I_p = Pole position = 31^*

J_p = Pole position = 31^*

RED = Distance from pole to equator in grid mesh lengths = 31.205

*32 used on IBM 360/70 at NPS W. R. Church Computer Center.

APPENDIX G: Verification Score Formulae

From a contingency table and associated information the Heidke Skill Score (HSS) and Threat Score (TS) can be calculated:

		EVENT ESTIMATED		
		YES	NO	
EVENT OBSERVED	YES	A	C	Total (T) = A + B + C + D
	NO	B	D	No. of Correct Forecast (FC) = A + D

$$HSS = \frac{FC - EX}{T - EX} \qquad \text{Range: } \frac{-2BC}{B^2 + C^2} \leq HSS \leq 1$$

where $EX = \frac{(A+B)(A+C) + (D+B)(D+C)}{T}$, No. of expected correct forecasts due to chance.

$$TS = \frac{A}{T-D} = \frac{A}{A+B+C} \qquad \text{Range: } 0 \leq TS \leq 1$$

Both scores indicate more skill with larger positive values.

The Probability Score (PS) is from that given by Panofsky and Brier (1958) and may be written as (Renard, 1975):

$$PS = \frac{2}{N}\left[\sum_{i=1}^{n_o} p_i^{\,2} + \sum_{j=1}^{n_1} (1 - p_j)^2\right]$$

Range: $0 \leq PS \leq 2$

where

N = Total number of cases

n_o = Total number of non-events

p_i = Associated probability value for the non-event

n_1 = Total number of events

p_j = Associated probability value for the event

The closer to zero, the greater the skill.

TABLE I. Abridged version of internationally used weather-code figures and definitions for reporting present and past weather and low clouds in the surface synoptic report (U. S. Departments of Commerce, Defense, and Transportation, 1969).

Present Weather

Code Value	Definition
00-03	Characteristic change of the state of the sky (cloud) during the past hour.
04-09	Haze, dust, sand, or smoke.
10	Deep light fog.
11-12	Shallow heavy fog.
13-17	Lightning, thunder, or precipitation within sight, not reaching the ground.
18-19	Squall(s), funnel cloud(s) during the past hour.
20	Drizzle during the past hour.
21-23	Rain, snow, or rain and snow during the past hour.
24	Freezing drizzle during the past hour.
25-27	Shower(s) during the preceding hour.
28	Fog during the past hour.
29	Thunderstorm during the past hour.

Present Weather

Code Value	Definition
30-39	Duststorm, sandstorm, drifting or blowing snow.
40	Fog at distance, but not at station during the past hour (visibility less than 1 km).
41-49	Deep heavy fog at the time of observation (visibility less than 1 km).
50-59	Drizzle, or drizzle and rain.
60-63	Slight to moderate rain.
64-65	Heavy rain.
66	Slight freezing rain.
67	Moderate or heavy freezing rain.
68	Slight rain or drizzle and snow.
69	Moderate or heavy rain or drizzle and snow.
70-79	Solid precipitation not in showers.
80-99	Showery precipitation or precipitation with current or recent thunderstorms.

TABLE I. (continued)

Past Weather

Code Value	Definition
0	Cloud covering ½ or less of sky throughout the period.
1	Cloud covering more than ½ of sky during part of period.
2	Cloud covering more than ½ of sky throughout the period.
3	Sandstorm, or duststorm, or blowing snow.
4	Heavy fog, thick haze, or smoke.
5	Drizzle
6	Rain
7	Snow, rain and snow mixed, or ice pellets.
8	Shower(s)
9	Thunderstorm, with or without precipitation.

Low Cloud Type

Code Value	Definition
0	No low clouds
1	Ragged cumulus of fair weather.
2	Generally towering cumulus.
3	Cumulonimbus without cirriform or anvil tops.
4	Stratocumulus formed by cumulus spreading out.
5	Stratocumulus not formed by cumulus spreading.
6	Stratus or fractostratus.
7	Fractostratus of bad weather.
8	Cumulus and stratocumulus, with bases at different levels.
9	Cumulonimbus with cirriform top.
/	Low cloud obscured.

Visibility

90	Less than 50 m
91	0-199 m
92	200-499 m
93	500 m - 0.99 km
94	1 - 1.99 km
95	2 - 3.99 km
96	4 - 9.99 km
97-99	equal to or greater than 10 km.

TABLE II. Listing and description of the elements of the visibility-weather group in the synoptic reports used to identify the existence of marine fog in earlier studies. (After Willms, 1975).

Fog related weather element	Symbolic letter(s)	Code figure(s)	Description	Depth of fog at sea(ft)	Visibility (km)	Related VV code figure(s)	Time of Occurrence
Present weather	ww	10	deep light fog at station	$\geq$ 33	1-10	93-96	At observation
		11	shallow heavy fog at station	< 33	< 1	90-93	At observation
		12	shallow heavy fog at station	< 33	< 1	90-93	At observation
		28	heavy fog at station	$\geq$ 33	< 1*	90-93*	Within one hour of observation but not at observation
		40	heavy fog at a distance from station	$\geq$ 33	< 1	90-93	At observation
		41-49	heavy fog at station	$\geq$ 33	< 1	90-93	At observation
Past weather	W	4	heavy fog or haze or smoke	$\geq$ 33	< 1*	90-93*	In the period one to six hours before observation
Horizontal visibility	VV	90-94**			< 2		At observation
		95,96**			2-10		At observation

* At time of visibility restriction indicated by present or past weather code figure.
**Visibility codes used to identify fog when ww(W) is not 10, 11, 12, 28, or 40-49(4).

TABLE III. Groupings and symbols used in FOGCAT categorization scheme. See Table IV.

Present Weather(ww)		Past Weather(W)		Low Cloud (CL)	
Symbol	Associated ww Codes	Symbol	Associated W Codes	Symbol	Associated CL Codes
41G	41-49	4	4	6	6
10G	10,28,40	4,5	4,5	5,7	5,7
11G	11,12,20,24	5G	0,1,2,5	B	/
50G	50-59	2G	0,1,2	*	any CL not listed above
60G	60-63,66,68	*	any W not listed above		
*	any ww not listed above				

G = Group.   B = Low clouds obscurred.

TABLE IV. Scheme for categorizing observations according to likelihood of fog (FOGCAT). See Table III for symbols. Number of July 1976 North Pacific Ocean observations in each subcategory stratified by visibility code.

Major Category	Sub-Category	Present Weather (ww)	Past Weather (W)	Low Cloud Type (CL)	Number of Visibility (VIS) Observations by VIS Code All (90-99)	Fair (94-95)	Poor (90-93)
Strong	a1	41G	4,5	6	66	19	32
Foggers	a2	"	"	B	466	83	360
= S	b1	"	2G	6	24	7	2
	b2	"	"	B	28	6	14
	b3	10G	4,5	6	51	9	2
	b4	"	"	B	36	12	16
	c1	41G	*	6	2	1	1
	c2	"	4,5	5,7	26	5	13
	c3	"	"	*	64	14	39
	c4	10G	2G	6	30	8	2
Total S cases:					793		
Foggers	d1	41G	*	B	21	3	17
= F	d2	"	2G	5,7	12	2	3
	d3	50G	4	6	11	3	0
	d4	"	"	B	13	5	6
	d5	10G	*	6	3	2	0
	d6	"	2G	B	13	4	1
	d7	"	4	5,7	14	2	1
	e1	41G	*	"	5	2	2
	e2	"	2G	*	14	4	5
	e3	50G	4	5,7	3	0	0
	e4	10G	*	B	1	0	1
	e5	"	4	*	37	9	1
	e6	11G	4	6	6	0	0
	e7	"	"	B	7	2	1

TABLE IV. (continued)

	f1	41G	*	*	2	0	1
	f2	50G	4	*	1	0	0
	f3	10G	5G	5,7	18	3	0
	f4	11G	"	6	7	0	1
	f5	"	"	B	12	1	0
F	g1	10G	*	5,7	2	0	1
	g2	"	5G	*	24	3	0
	g3	11G	*	6	1	0	0
	g4	"	4	5,7	6	2	1
	g5	"	"	*	1	1	0
	h1	"	*	B	0	0	0
	h2	"	5G	5,7	16	2	1
	i1	10G	*	*	2	0	1
	i2	11G	*	5,7	2	2	0
	j1	"	5G	*	8	2	0
Total F cases:					262		
Past/Weak	k1	50G	5G	6	61	-	8
Foggers	k2	60G	4	6	3	-	0
= P	ℓ1	"	"	B	4	-	2
	ℓ2	*	"	6	32	-	2
	m1	50G	*	6	6	-	1
	m2	*	4	B	31	-	12
	n1	*	5G	6	313	-	2
	o1	60G	4	5,7	1	-	0
	o2	*	4	5,7	39	-	0
	p1	60G	4	*	1	-	0
	p2	*	*	6	26	-	0
	p3	*	4	*	61	-	1
Total P cases:					578		

TABLE IV. (continued)

Maybe	q1	50G	5G	B	51	-	-
Foggers	q2	"	"	5,7	29	-	-
= M	q3	"	*	5,7	7	-	-
	q4	"	5G	*	19	-	-
	q5	11G	*	*	0	-	-
	q6	60G	5G	6	14	-	-
	q7	"	*	6	21	-	-
	r1	50G	*	B	7	-	-
	r2	"	*	*	3	-	-
	r3	60G	5G	B	5	-	-
	r4	"	"	5,7	19	-	-
	r5	"	*	B	19	-	-
	r6	"	*	5,7	50	-	-
Total M cases:					244		
Non-Foggers	u1	60G	5G	*	8	-	0
= N	u2	"	*	*	17	-	1
	v1	*	5G	B	192	-	2
	w1	*	*	B	13	-	6
	x1	*	*	5,7	44	-	9
	y1	*	5G	5,7	687	3	2
	y2	*	5G	5,7	1541	5	2
	z1	*	*	*	102	1	1
Total N cases:					2604		

Note: A dash in a visibility scheme indicates that particular count was not done.

TABLE V. Major fog categories and sub-category fog groups with associated Base and Fog Scores as a function of visibility.

Major Category	Visibility Code Values: 96-99 (Good)	94-95 (Fair)	90-93 (Poor)	Base Score	Fog Score
	Subcategory Groups				
			a	580	100.0
		a	b	560	96.6
	a	b	c	540	93.1
S	b	c	d	520	89.7
	c	d	e	500	86.2
	d	e	f	480	82.8
	e	f	g	460	79.3
	f	g	h	440	75.9
F	g	h	i	420	72.4
	h	i	j	400	69.0
	i	j		380	65.5
	j		k	360	62.1
	k	k	ℓ	340	58.6
	ℓ	ℓ	m	320	55.2
	m	m	n	300	51.7
P	n	n	o	280	48.3
	o	o	p	260	44.8
	p	p		240	41.4
	q	q	q	220	37.9
M	r	r	r	200	34.5
not	s	s	s	180	31.0
used	t	t	t	160	27.6
			u	140	24.1
	u	u	v	120	20.7
	v	v	w	100	17.2
	w	w	x	80	13.8
N	x	x	y	60	10.3
		y	z	40	6.9
	y	z		20	3.4
	z			0	0.0

TABLE VI. Correlation coefficients between predictor parameters and Fog Score (predictand), and range and mean values of parameters, July 1976, North Pacific Ocean.

	cc	Mean**	Min**	Max**
FTER	0.3471	0.18	-0.09	1.02
CLIMO	0.4173	24.6	0.0	59.3
EHF	-0.4605	3.2	-12.6	23.4
SHF	-0.3484	-4.7	-23.8	6.0
SEHF	-0.4382	-1.4	-36.4	24.0
THF	-0.3245	-40.9	-77.5	-11.7
SOLARAD	0.0012	46.3	25.7	87.6
PS	-0.2336	1014.1	981.9	1033.9
EX	-0.2933	15.5	7.3	30.6
EAIR	-0.2492	15.5	5.9	36.0
TX	-0.2893	15.9	5.4	27.2
TAIR	-0.3335	14.9	4.8	29.5
T925	-0.1302	14.1	-3.5	26.3
TSEA	-0.3563	13.5	4.1	27.3
SSTA	-0.1839	-0.8	-4.1	2.9
VVWW	0.1364	14.1	0.5	64.7
DDWW*	0.0923	20.6	-3.7	39.6
u	0.1311	2.9	-19.2	28.5
v	0.1590	1.7	-22.8	21.0
CAPU	0.0622	1.2	-22.7	17.3
CAPV	0.1281	-3.1	-31.3	20.0

	cc	Mean**	Min**	Max**
HW	0.0579	4.6	-0.3	21.5
PPW	-0.0133	8.3	-1.0	20.3
PDW*	-0.0437	18.8	-4.0	35.2
SPW	0.0053	5.8	-2.8	23.4
SDW*	-0.0354	11.9	-5.5	36.0
WCP	0.0516	0.4	-0.3	6.5
THETAX	-0.2766	287.5	277.5	299.3
THETAR	-0.3253	286.5	276.6	300.4
STABX	-0.2421	-0.06	-0.19	0.05
STABR	-0.2771	-0.08	-0.23	0.08
ASTDX	0.3189	2.4	-2.4	9.3
ASTDR	0.1022	1.4	-4.5	7.2
ADTSEA	0.1529	0.04	-0.75	0.91
ADTX	0.1691	0.04	-0.70	0.71
ADTAIR	0.1907	0.05	-0.74	0.76
AASTDX	-0.0011	0.001	-0.51	0.40
AASTDR	0.0784	0.006	-0.82	0.64
FOG SCORE	1.0000	32.7	0.0	100.0

* Cyclic variable
**Data base for these are the 4481 values interpolated to the reporting ship positions.

TABLE VII. Regression equation predictor parameters and coefficients, and associated explained predictand variances (R^2) for stepwise selection, whole area, North Pacific Ocean (about 30-60 N), July 1976.

Step # / Eq. # :	0	1	2	3	4
Regression Coefficients for:					
Y Intercept (YI)	32.7371	45.6634	31.6268	28.0224	32.7201
EHF		-3.9905	-2.8894	-2.5682	-2.9108
CLIMO			0.4253	0.4848	0.4449
v				0.6597	0.7377
ASTDR					-1.9225
R^2	0.4420	0.5603	0.5683	0.5723	0.5751
ΔR^2		0.1183	0.0080	0.0040	0.0028

Eq.	5	6	7	8	9	9.9
YI	19.1988	26.3068	29.0414	31.5562	35.8282@	26.0224
EHF	-3.0833	-2.4184	-1.8325	-1.7033	-1.7501@	-1.7501@
CLIMO	0.6215	0.4975	0.4475	0.4080	0.4016@	0.4016@
v	0.5749	0.5582	0.5576	0.3235	0.3340	0.3340
ASTDR	-2.4378	-3.7142	-3.9904	-4.1775	-4.1184	-4.1184
EAIR	0.6945	2.7912	3.0329	2.9730	2.8612	2.8612
TSEA		-2.7223	-3.8795	-3.9930	-3.8860@	-3.8860@
T925			0.6607	0.6604	0.6884	0.6884
ADTAIR				15.6933**	16.1710	16.1710
PDW					0.2203	0.2203
R^2	0.5781	0.5850	0.5861	0.5872	0.5883	N/A
ΔR^2	0.0030	0.0060	0.0011	0.0011	0.0011	N/A

@ Most Significant Variables (based on ΔR^2 greater than 0.005).
**This value not used during "skill" calculations; 16.171 is due to copying error.

TABLE VIII. Regression equation predictor parameters and coefficients, and associated explained predictand variances (R^2) for special treatment of climatology parameter (final-step form), whole area, North Pacific Ocean (about 30-60 N), July 1976.

Equation 9T

Fog Score transformed (T)
(Fog Score = Fog Score - CLIMO)
before regression.

Regression Coefficient	Variable (in entry order)	ΔR^2
1.	CLIMO	-
-1.8328	EHF*	0.0299
+2.9127	EAIR*	0.0279
-2.0207	TAIR*	0.0154
+0.5283	v	0.0046
-1.3244	ASTDR	0.0022
-	YI upon entry	0.0557
-	YI upon removal	-0.0004

Final R^2 = 0.1353

FTER, DDWW, (SEHF, THF, SHF, CAPU, CAPV)** not in the use list.

Equation 9NC

Regression Coefficient	Variable (in entry order)	ΔR^2
55.9906	YI*	0.4420
-1.8859	EHF*	0.1183
-4.4919	ASTDR	0.0035
+21.0621	ADTAIR	0.0042
-4.9522	TSEA	0.0028
+2.9131	EAIR*	0.0091
+0.9988	T925	0.0028
-0.2333	PDW	0.0012
+0.2698	v	0.0004

Final R^2 = 0.5843

CLIMO, FTER, DDWW, (SEHF, THF, SHF, CAPU, CAPV)** not in the use list.

* Most Significant Variables (based on $\Delta R^2 > 0.005$).

** Omitted through error.

TABLE IX. Regression equation predictor parameters and coefficients, and associated explained predictand variances (R^2), final-step form, for two sub-areas, North Pacific Ocean, July 1976.

Equation 39

Based on 1504 observations south of 40 N.

Regression Coefficient	Variable (in entry order)	ΔR^2
-0.9826	EHF*@	0.0929
0.6595	CLIMO*	0.0246
0.5560	EAIR*	0.0089
-1.4355	SSTA	0.0025
-0.1608	SDW	0.0016
-74.0931	STABR*	0.0018
-	YI upon entry	0.2842
-	YI upon removal	-0.0003
	HW upon entry	0.0043
	HW upon removal	-0.0014

Final R^2 = 0.4219

Equation 40

Based on 2977 observations at and north of 40 N.

Regression Coefficient	Variable (in entry order)	ΔR^2
21.8849	YI*	0.5337
-2.0569	EHF*	0.0601
-7.3865	ASTDR*	0.0058
0.2945	CLIMO	0.0020
-7.6194	TSEA*	0.0165
0.7898	T925	0.0014
0.5861	v	0.0011
-26.5505	AASTDX	0.0010
	ADTSEA upon entry	0.0047
	ADTSEA upon removal	-0.0004

Final R^2 = 0.6278

FTER, DDWW, (SEHF, THF, SHF, CAPU, CAPV)** not in use list for both equations.

* Most Significant Variables (based on $\Delta R^2 > 0.005$).
** Omitted through error.
@ Not best equation (39) possible. A full use list run (not shown) made late in the study gave SEHF a higher initial correlation to Fog Score.

TABLE X. Heidke Skill and Threat Scores, whole area, North Pacific Ocean (about 30-60 N), July 1976. FOGCAT designators S and F used to identify marine fog observations. See Table IV and text.

Predictor	Cutoff (Cut) (Per cent)	Skill Score	Threat Score
FTER	30	0.274	0.304
	70	.029	.023
CLIMO	30	.271	.325
	40	.232	.241
Eq 1	40	.340	.355
Eq 2	40	.355	.372
Eq 3	40	.346	.365
Eq 4	40	.350	.367
Eq 5	40	.361	.372
Eq 6	40	.376	.388
Eq 7	40	.378	.389
Eq 8*	40	.386	.394
Eq 9	40	.381	.392
	45	.383	.373
Eq 9.9	35	.380	.372
Eq 9T	45	.383	.373
Eq 9NC	40	.369	.384

Scoring performed on whole area data file; i.e., 4481 cases, of which 1055 are classified Foggers, using major categories S and F as criteria.

*Error in one variable's coefficient makes these results slightly suspect.

TABLE XI. Daily Heidke Skill Scores, whole area, North Pacific Ocean (about 30 - 60 N), July 1976. FOGCAT designators S and F used to identify marine fog observations. See Table IV and text.

DAY	Cases	Foggers	FTER Cut=30 (Per cent)	CLIMO =30	Eq. (9) =40
1	125	28	0.159	0.336	0.459
2	162	34	.119	.346	.273
3	145	35	.140	.245	.282
4	147	33	.132	.228	.379
5	152	39	.016	.149	.214
6	156	30	-0.060	.200	.172
7	148	27	.027	.160	.331
8	140	33	.050	.322	.332
9	160	32	.219	.326	.408
10	163	38	.459	.372	.540
11	132	25	.284	.285	.315
12	145	33	.319	.331	.442
13	159	32	.231	.190	.213
14	136	21	.010	.172	.211
15	160	34	.323	.386	.455
16	156	34	.228	.328	.363
17	141	31	.238	.200	.336
18	164	38	.292	.148	.402
19	165	40	.414	.264	.513
20	147	32	.450	.303	.446
21	138	24	.118	.162	.291
22	151	40	.407	.416	.438
23	148	40	.428	.378	.483
24	137	32	.488	.386	.539
25	143	45	.444	.367	.512
26	156	42	.455	.490	.451
27	146	41	.342	.251	.337
28	143	44	.348	.107	.337
29	157	49	.505	.212	.402
30	159	49	.267	.161	.421
Total	4481	1055			

CLIMO has more skill on 17 of the 30 days compared to FTER.
Eq.(9) has more skill on 24 of the 30 days compared to FTER.
Eq.(9) has more skill on 28 of the 30 days compared to CLIMO.
Eq.(9) has more skill on 23 of the 30 days compared to CLIMO and FTER.

TABLE XII. Daily Threat Scores, whole area, North Pacific Ocean (about 30-60 N), July 1976. FOGCAT designators S and F used to identify marine fog observations. See Table IV and text.

DAY	FTER Cut=30 (Per cent)	CLIMO =30	EQ. (9) =40
1	0.241	0.346	0.446
2	.202	.301	.306
3	.247	.321	.342
4	.229	.299	.385
5	.198	.276	.314
6	.134	.257	.247
7	.136	.224	.328
8	.194	.349	.350
9	.231	.328	.374
10	.421	.377	.491
11	.283	.305	.321
12	.339	.349	.421
13	.229	.250	.241
14	.135	.219	.231
15	.316	.379	.431
16	.262	.355	.375
17	.233	.269	.362
18	.265	.250	.400
19	.354	.325	.485
20	.412	.346	.424
21	.170	.229	.300
22	.400	.426	.439
23	.429	.408	.477
24	.464	.293	.509
25	.471	.427	.539
26	.457	.486	.458
27	.407	.353	.414
28	.388	.284	.410
29	.514	.347	.451
30	.314	.304	.456

CLIMO has more skill on 19 of the 30 days compared to FTER.
Eq.(9) has more skill on 29 of the 30 days compared to FTER.
Eq.(9) has more skill on 27 of the 30 days compared to CLIMO.
Eq.(9) has more skill on 26 of the 30 days compared to CLIMO and FTER.

TABLE XIII. Heidke Skill and Threat Scores, sub-areas, North Pacific Ocean (about 30-60 N), July 1976. FOGCAT designators S and F used to identify marine fog observations. See Table IV and text.

Predictor	Cut (Per cent)	Skill Score	Threat Score
Area: Northern Belt* (2977 observations; 948 foggers)			
FTER	30	0.233	0.335
	70	.026	.026
CLIMO	30	.151	.341
	40	.170	.259
Eq. (9)	40	.299	.412
	45	.322	.397
Eq. (40)	40	.306	.418
	45	.337	.412
Area: Southern Belt** (1504 observations; 107 foggers)			
FTER	30	0.156	0.133
	70	-0.001	.000
CLIMO	30	.067	.043
	40	.000	.000
Eq. (9)	35	.288	.213
	40	.247	.174
Eq. (39)	30	.283	.209
	35	.254	.173

* Northern Belt = whole area cases at or north of 40 N

**Southern Belt = whole area cases south of 40 N

TABLE XIV. Probability Scores (PS) for whole and sub-areas of the North Pacific Ocean (30-60 N), July 1976. FOGCAT designators S and F used to identify marine fog observations. See Table IV and text.

Whole Area

Predictor	PS	Max	Min	No. of observations with value below zero
FTER	0.350	1.02	-0.09	1183
FTER +0.02	.349	1.04	-0.07	292
FTER +0.05	.347	1.07	-0.04	21
CLIMO	.315	59.3	0.0	0
Eq. (1)	.323	96.	-48.	195
Eq. (2)	.319	87.	-36.	195
Eq. (3)	.317	87.	-33.	185
Eq. (4)	.317	88.	-35.	209
Eq. (5)	.315	94.	-37.	192
Eq. (6)	.313	85.	-53.	257
Eq. (7)	.312	88	-53.	262
Eq. (8)*	.312	88.	-52.	268
Eq. (9)	.311	89.	-50.	253
Eq. (9.9)	.290	79.	-60.	576
Eq. (9T)	.313	88.	-55.	261
Eq. (9NC)	.314	87.	-47.	277

Northern Belt (cases at or north of 40 N)

Predictor	PS	Predictor	PS
FTER	0.446	Eq. (9)	0.393
CLIMO	0.412	Eq. (40)	0.388

Southern Belt (cases south of 40 N)

FTER	0.162	Eq. (9)	0.149
CLIMO	0.124	Eq. (39)	0.135

*Error in coefficient makes result slightly suspect.

TABLE XV. Daily Probability Scores, whole area, North Pacific Ocean (about 30-60 N), July 1976. FOGCAT designators S and F used to identify marine fog observations. See Table IV and text.

DAY	FTER	CLIMO	Eq. (9)	Eq. (9.9)
1	0.384	0.281	0.291	0.272
2	.391	.318	.317	.289
3	.394	.341	.352	.326
4	.434	.305	.328	.293
5	.471	.369	.385	.364
6	.447	.299	.342	.246
7	.350	.279	.318	.272
8	.388	.314	.332	.308
9	.341	.276	.285	.260
10	.281	.301	.284	.271
11	.299	.270	.303	.262
12	.340	.291	.298	.270
13	.302	.309	.300	.280
14	.305	.259	.282	.245
15	.310	.265	.271	.253
16	.355	.299	.316	.288
17	.366	.308	.320	.296
18	.365	.328	.298	.288
19	.347	.314	.276	.265
20	.364	.305	.278	.259
21	.312	.282	.299	.257
22	.334	.337	.295	.297
23	.337	.326	.292	.289
24	.267	.370	.252	.228
25	.311	.351	.308	.307
26	.307	.297	.291	.282
27	.332	.366	.368	.341
28	.369	.390	.362	.355
29	.344	.394	.335	.336
30	.450	.391	.348	.354

CLIMO had more skill on 22 of the 30 days compared to FTER.
Eq. (9) had more skill on 27 of the 30 days compared to FTER.
Eq. (9) had more skill on 14 of the 30 days compared to CLIMO.
Eq. (9) had more skill on 13 of the 30 days compared to CLIMO and FTER.
Eq.(9.9) had more skill on 29 of the 30 days compared to FTER.
Eq.(9.9) had more skill on 30 of the 30 days compared to CLIMO.
Eq.(9.9) had more skill on 27 of the 30 days compared to Eq.(9).
Eq.(9.9) had more skill on 26 of the 30 days compared to FTER, CLIMO, and Eq.(9).

TABLE XVI. Total observation counts, and fog observation counts and frequencies, by probability class, whole area (about 30-60 N), July 1976. FOGCAT designators S and F used to identify marine fog observations. See Table IV and text.

	PREDICTOR								
	Eq.(9)			CLIMO			FTER		
	Number of reports			Number of reports			Number of reports		
		Fog			Fog			Fog	
Probability (p) Class	Total	No.	%	Total	No.	%	Total	No.	%
$0.0 \le p < .10$	586	7	1.2	1127	46	4.1	2345	330	14.1
$.10 \le p < .20$	522	26	5.0	582	84	14.4	454	91	20.0
$.20 \le p < .30$	722	53	7.3	911	210	23.0	320	70	21.9
$.30 \le p < .40$	897	178	19.8	1061	355	33.5	418	128	30.6
$.40 \le p < .50$	919	333	36.2	663	293	44.2	452	212	46.9
$.50 \le p < .60$	606	321	53.0	137	67	48.9	244	107	43.8
$.60 \le p < .70$	179	102	57.0	0	0	0	208	92	44.2
$.70 \le p < .80$	46	31	67.4	0	0	0	20	13	65.0
$.80 \le p < .90$	4	4	100.0	0	0	0	12	7	58.3
$.90 \le p \le 1.00$	0	0	0	0	0	0	8	5	62.5
TOTAL	4481	1055	23.5	4481	1055	23.5	4481	1055	23.5

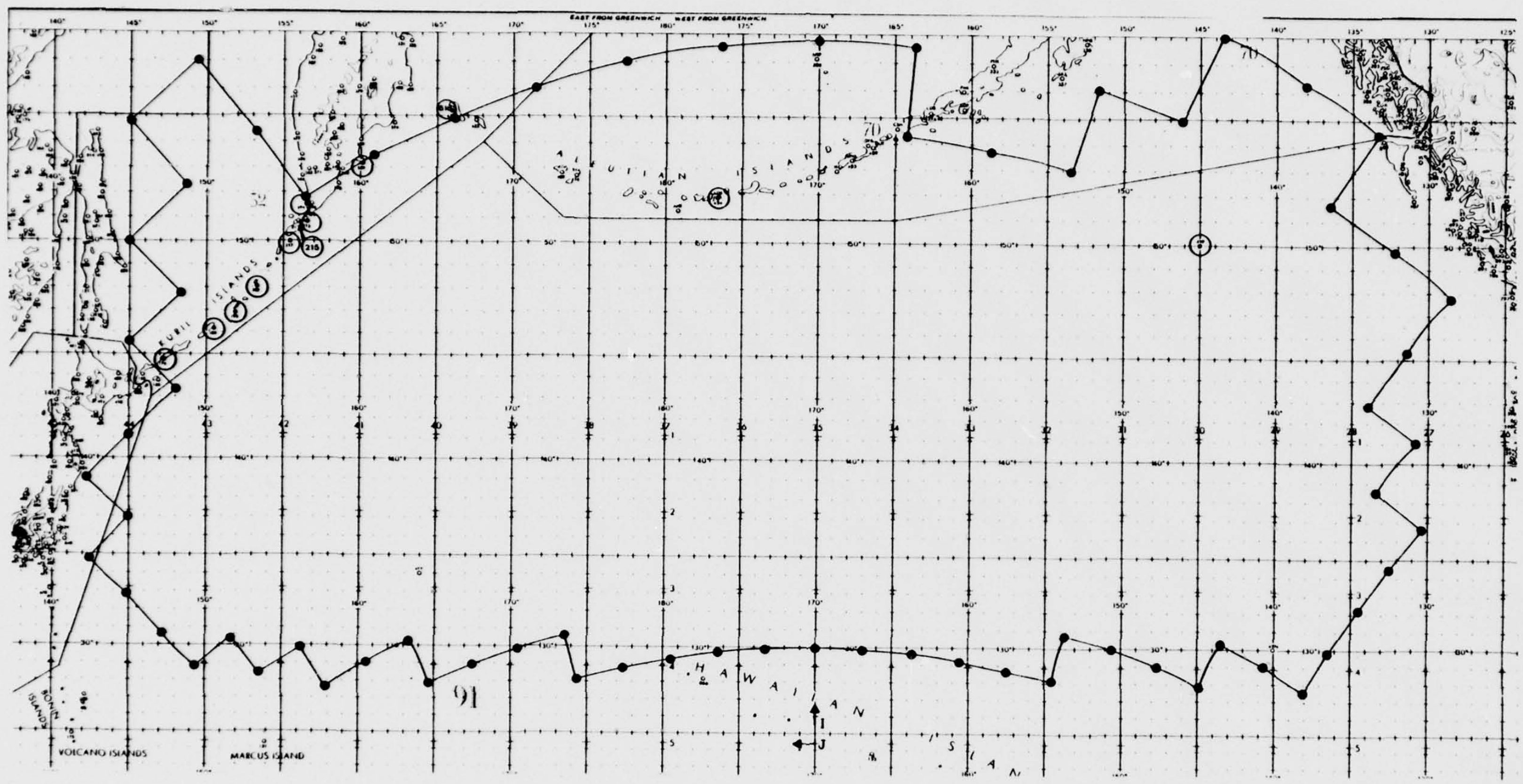

Figure 1. Study Area on Mercator projection. Land stations used in study and Ocean-Weather-Ship P are encircled.

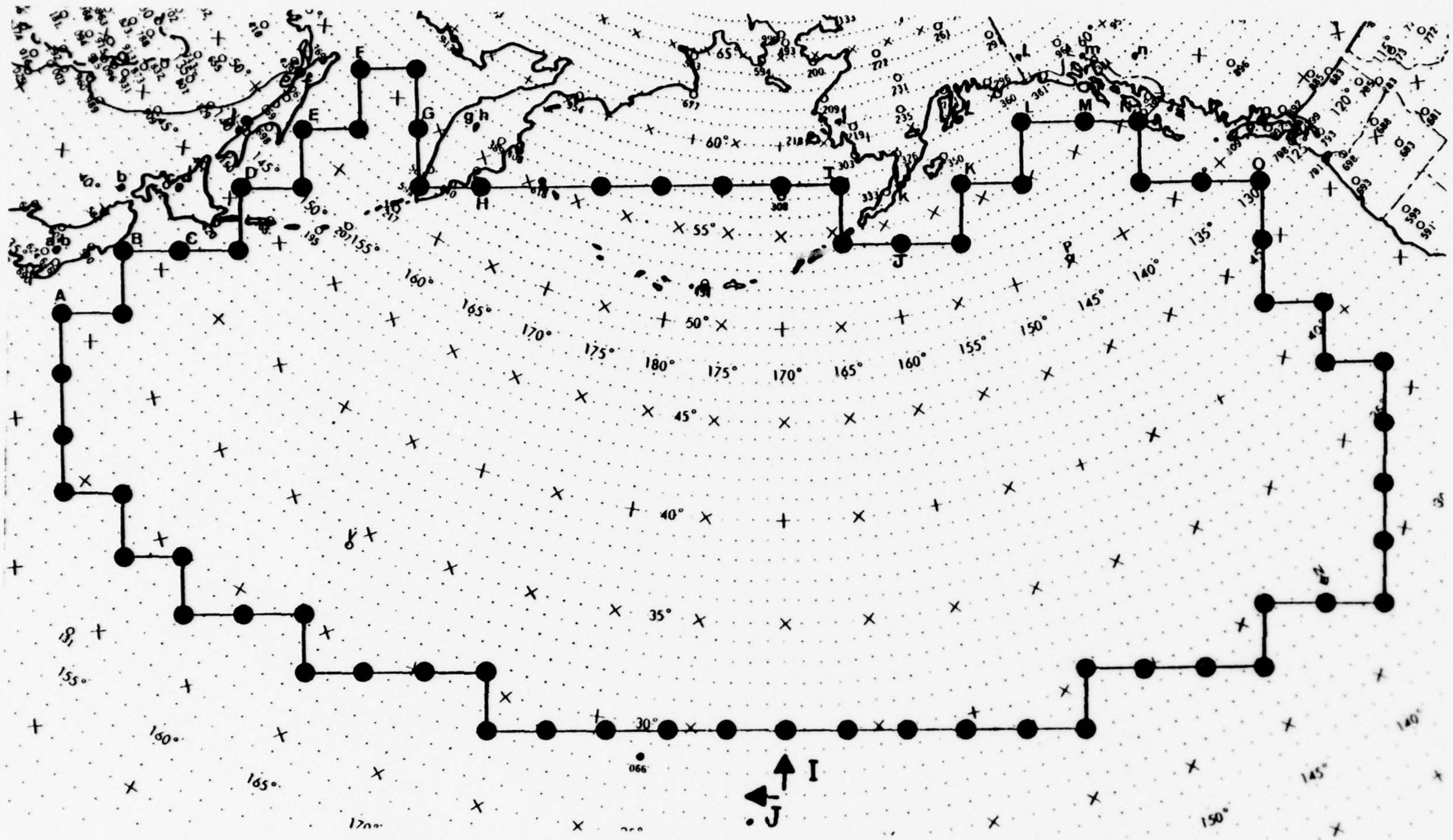

Figure 2. Study Area on Polar Stereographic projection. Grid point locations involved in advection computations requiring bogusing are labeled. See Appendix D.

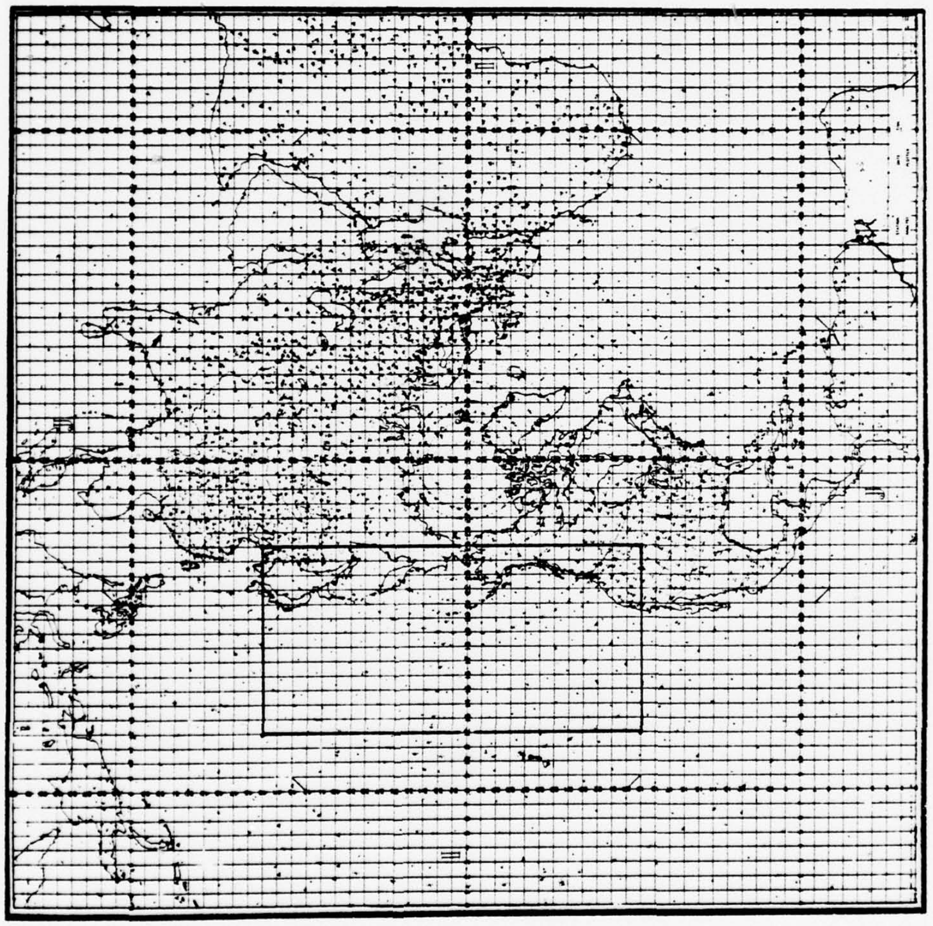

Figure 3. Fleet Numerical Weather Central's 63x63 grid, with outline of North Pacific Ocean rectangular grid area used in study. See text.

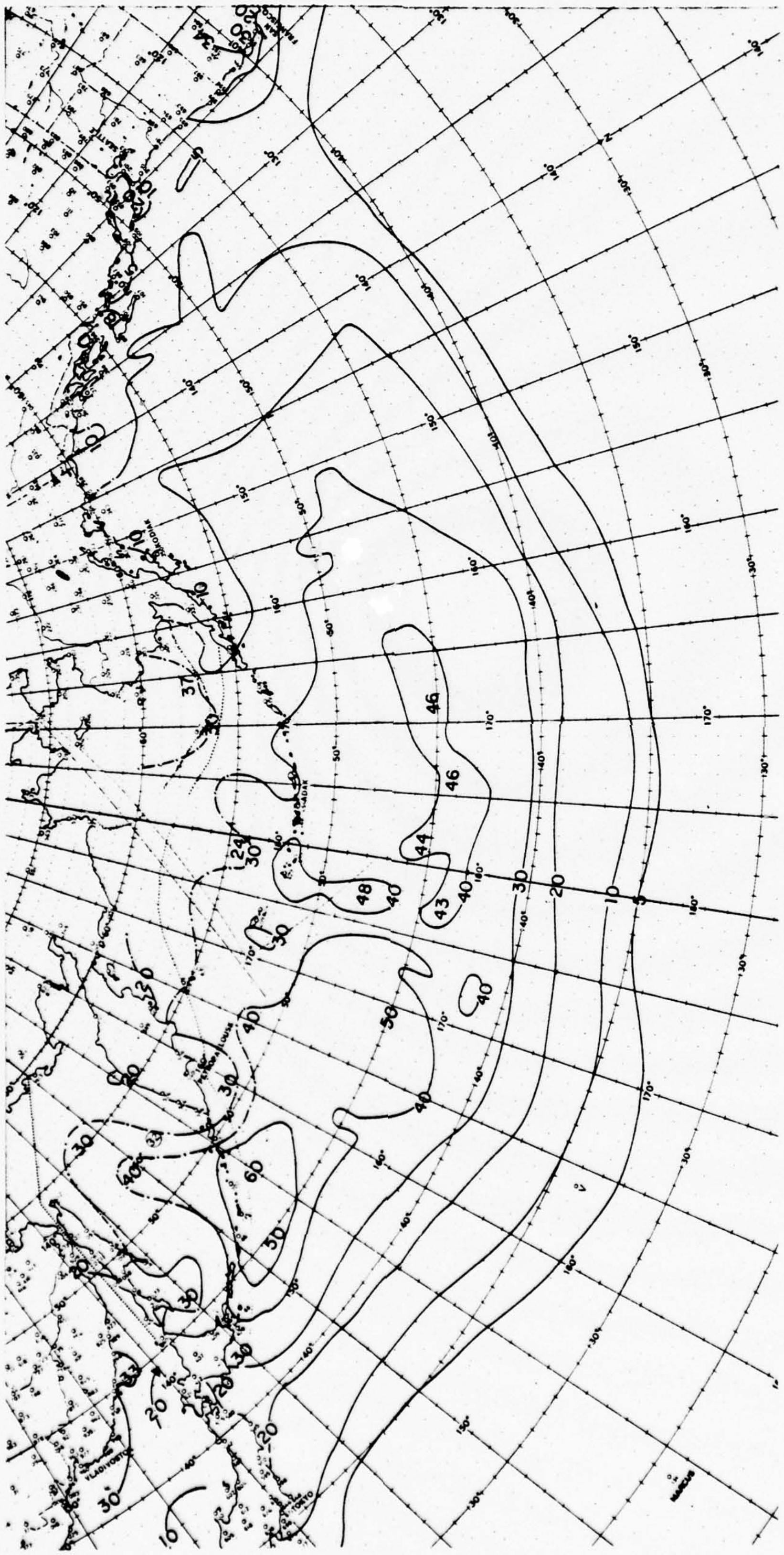

Figure 4. Naval Postgraduate School's fog frequency climatology (percent) for July. (After Willms, 1975).

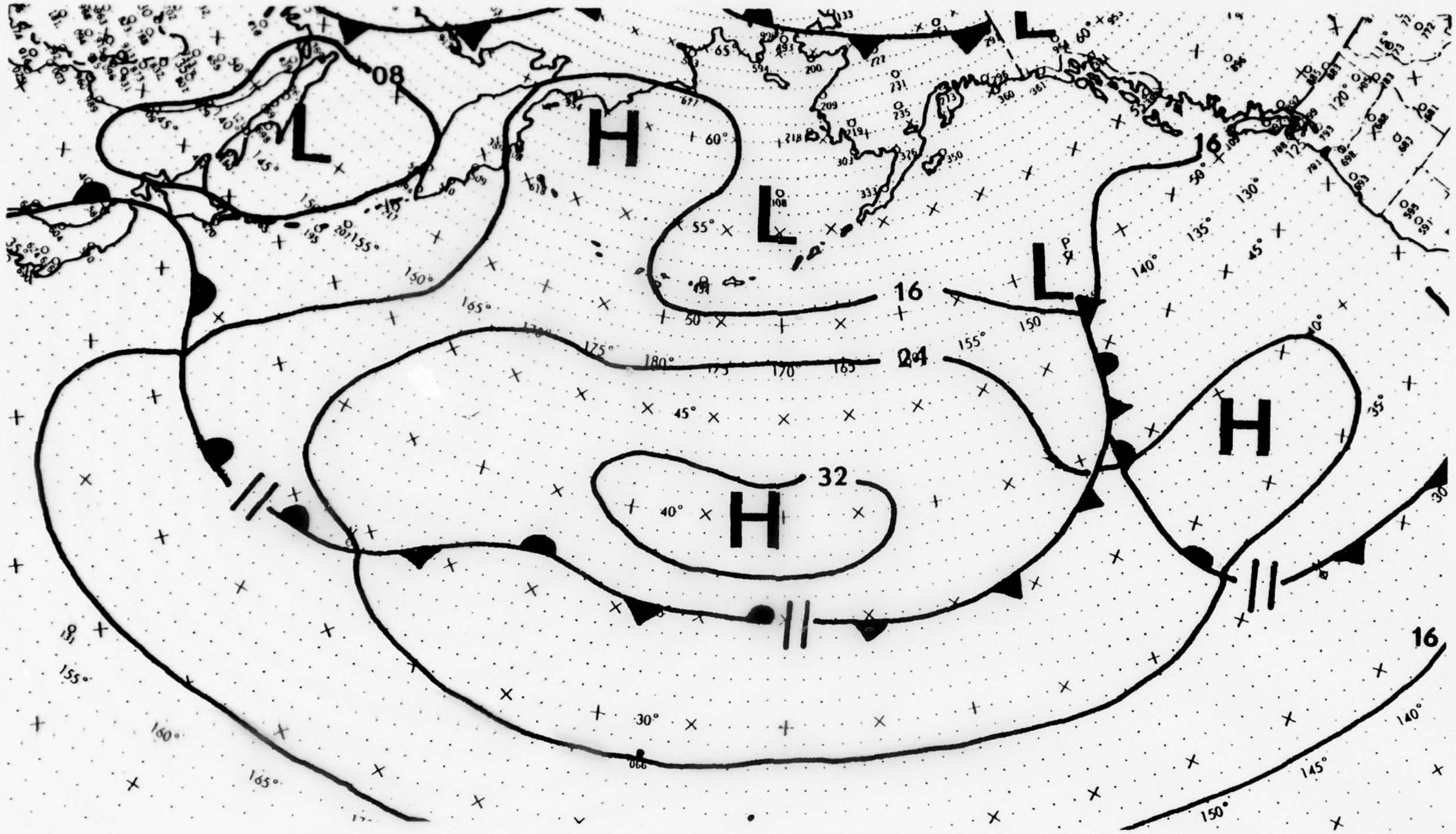

Figure 5. National Meteorological Center's sea-level pressure analysis (tens, units, mb), 0000 GMT, 12 July 1976.

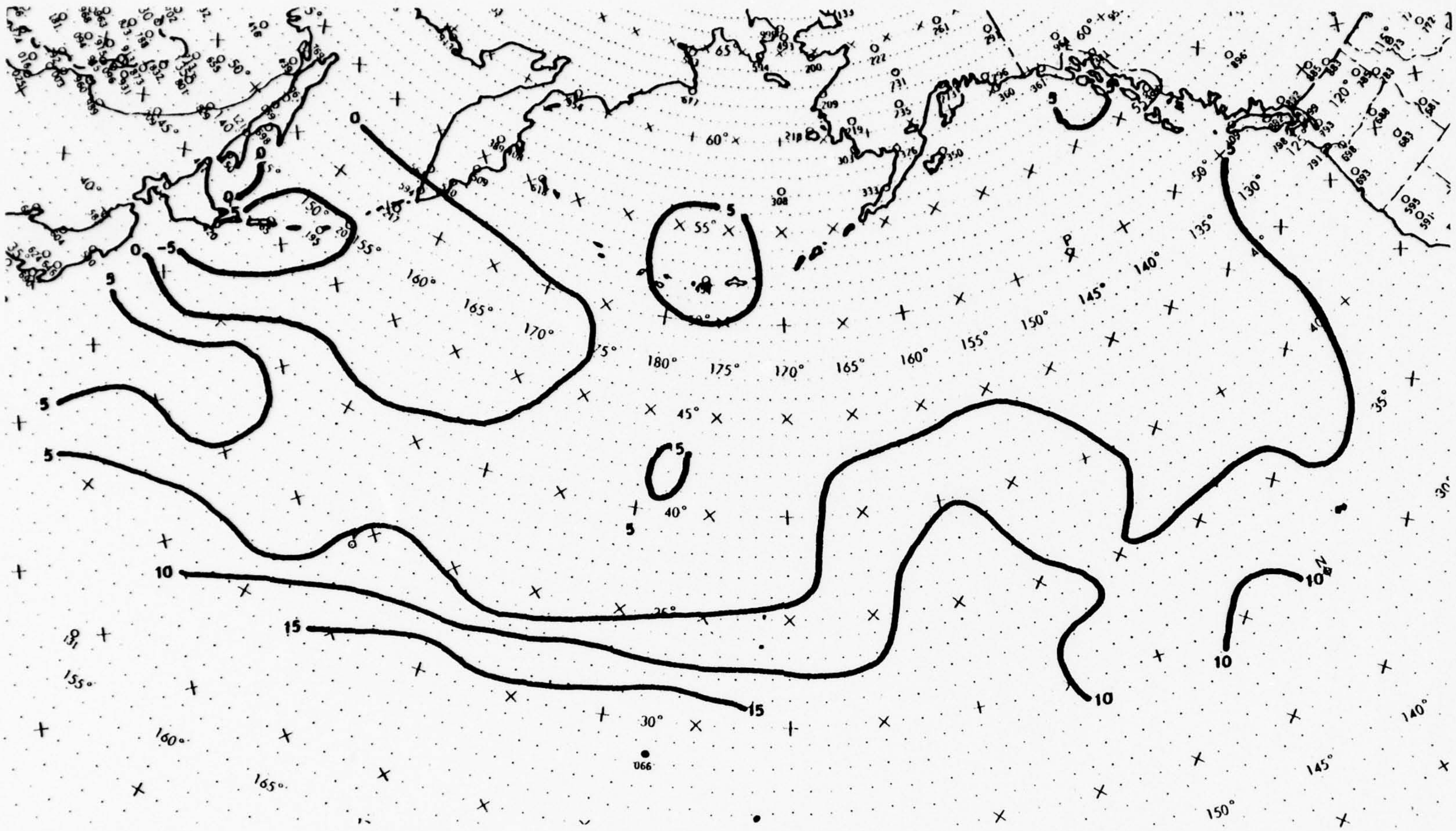

Figure 6. Analysis of FNWC's evaporative heat flux grid point data ($g \cdot {}^{\circ}C/cm^2 \cdot$ depth) for 0000 GMT, 12 July 1976.

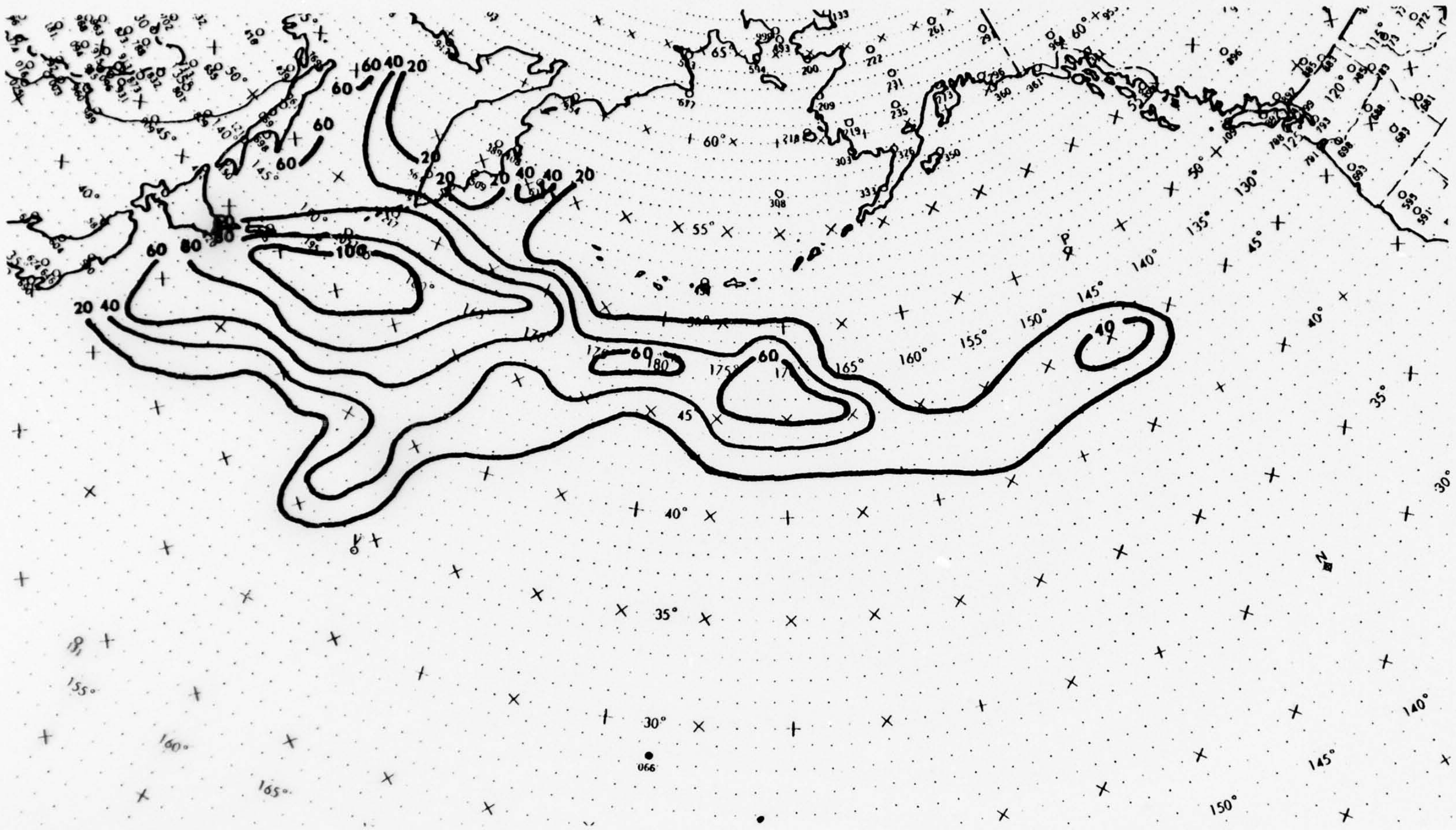

Figure 7. Analysis of FNWC's fog probability (FTER) grid point data (per cent) for 0000 GMT, 12 July 1976.

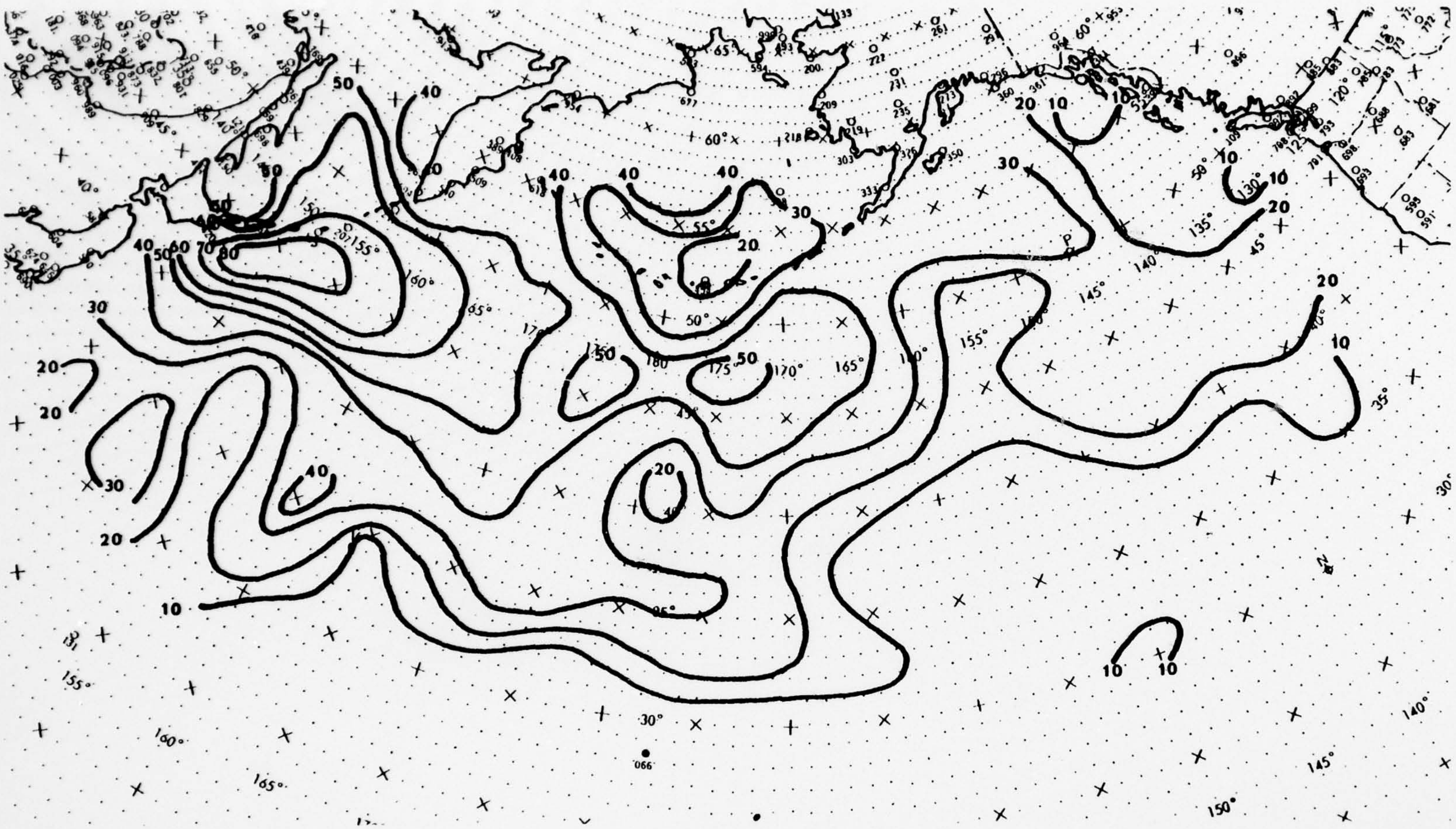

Figure 8. Analysis of Fog Score grid point data [from regression equation (9)] (per cent) for 0000 GMT, 12 July 1976.

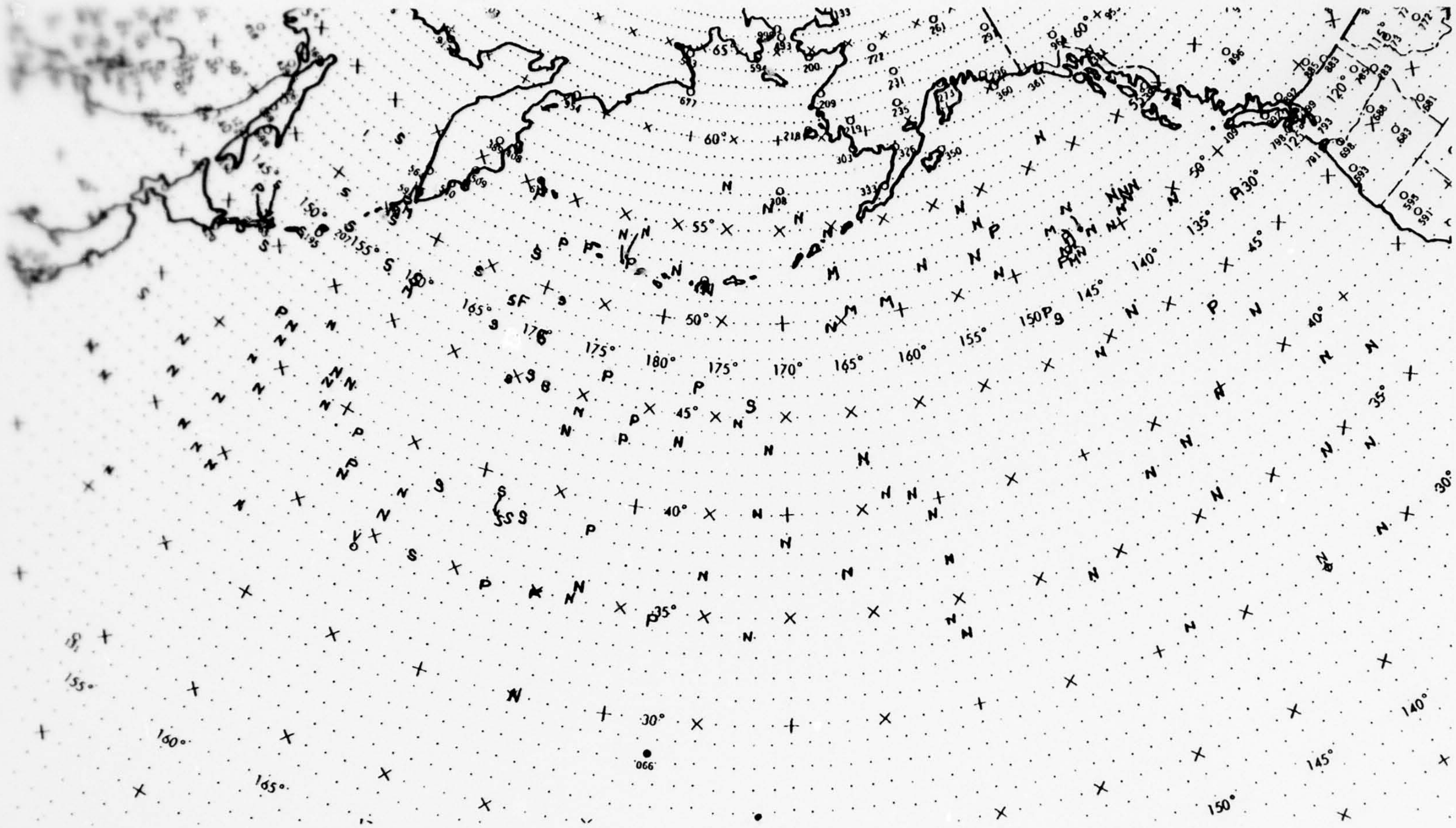

Figure 9. Categorized synoptic observations (FOGCAT) for 0000 GMT, 12 July 1976. S = Strong Foggers, F = Foggers, P = Past/ Weak Foggers, M = Maybe Foggers, N = Non-Foggers.

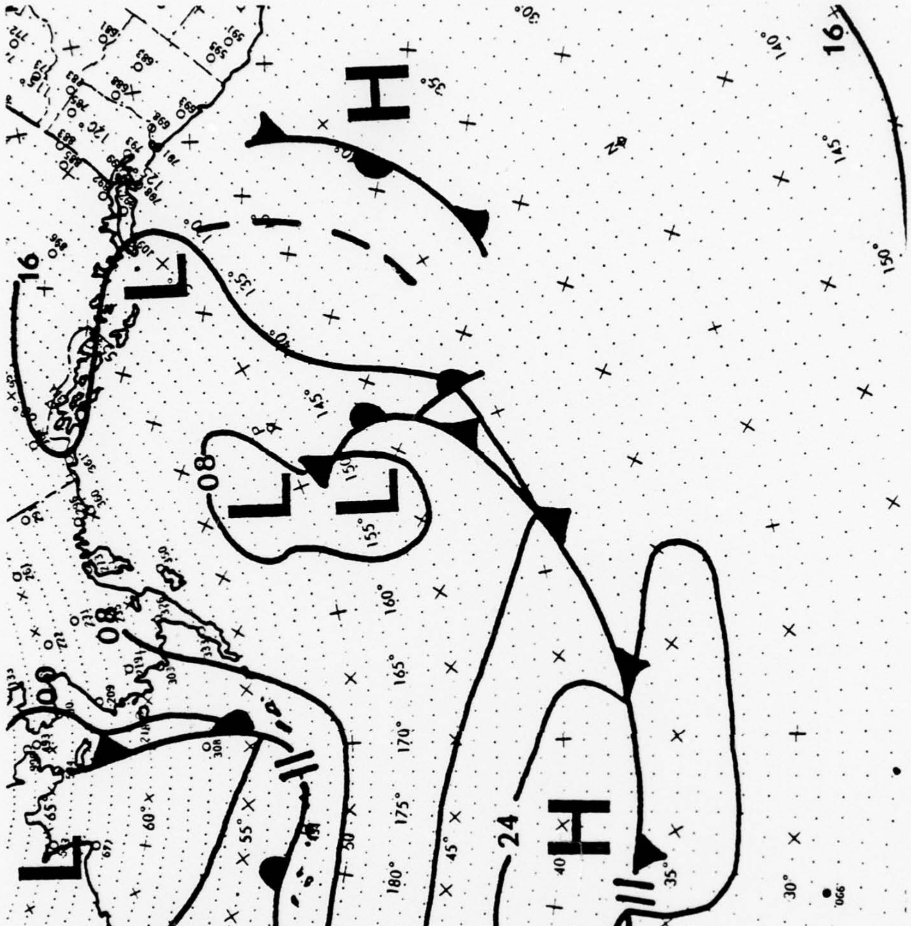

Figure 10. National Meteorological Center's sea-level pressure analysis (tens, units, mb), 0000 GMT, 24 July 1976.

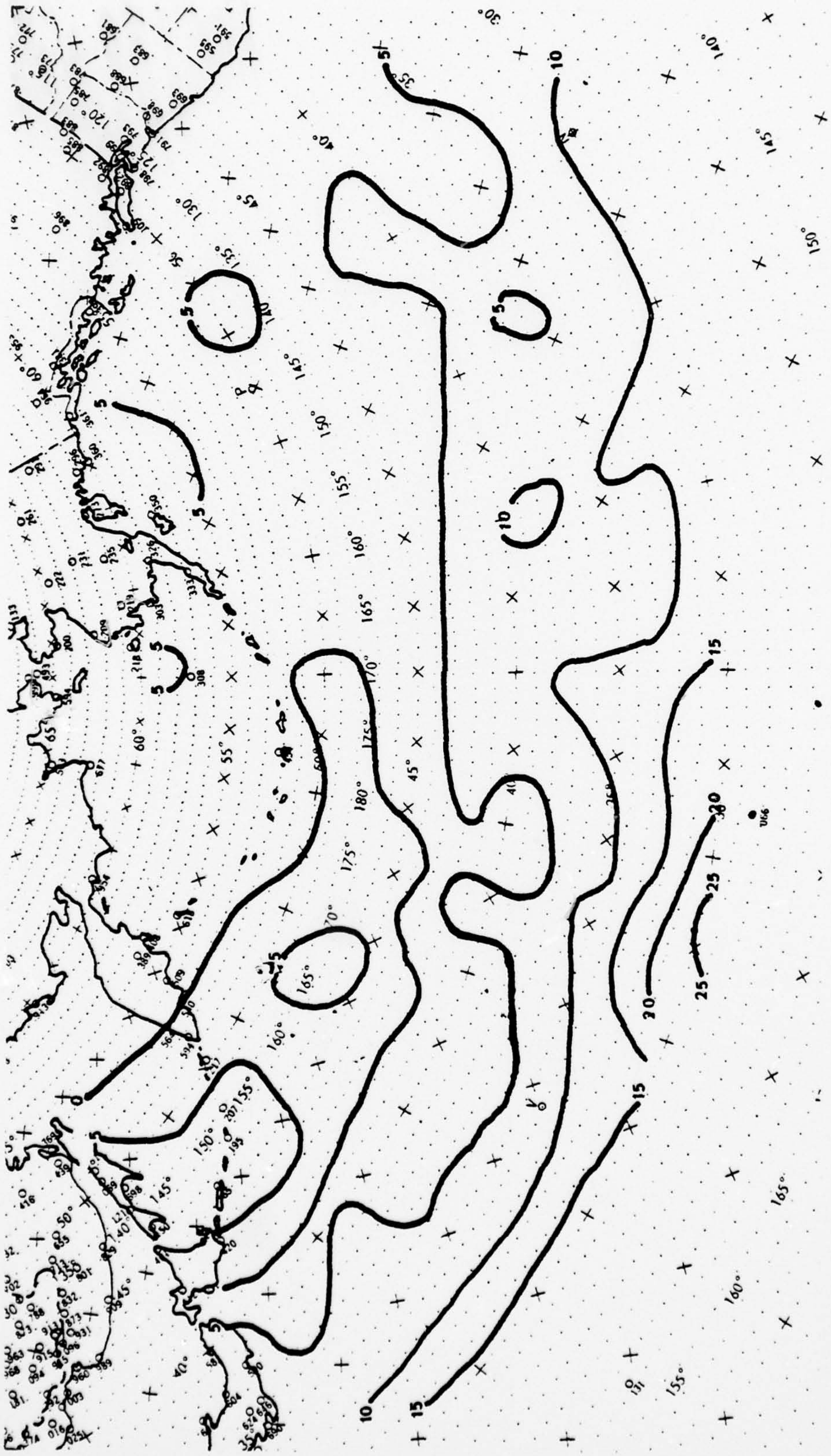

Figure 11. Analysis of FNWC's evaporative heat flux grid point data ($g \cdot {}^\circ C/cm^2 \cdot$ depth) for 0000 GMT, 24 July 1976.

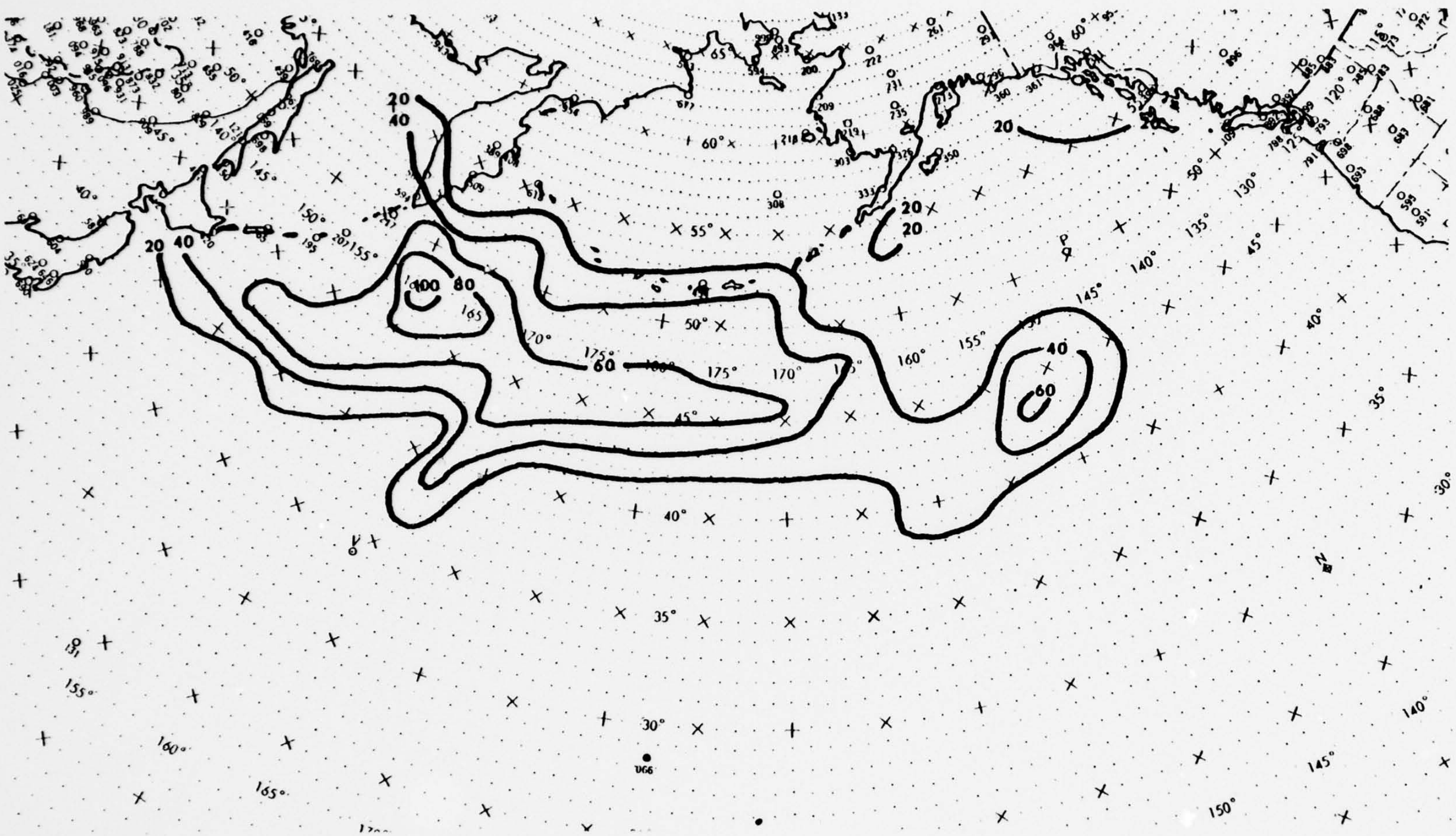

Figure 12. Analysis of FNWC's fog probability (FTER) grid point data (per cent) for 0000 GMT, 24 July 1976.

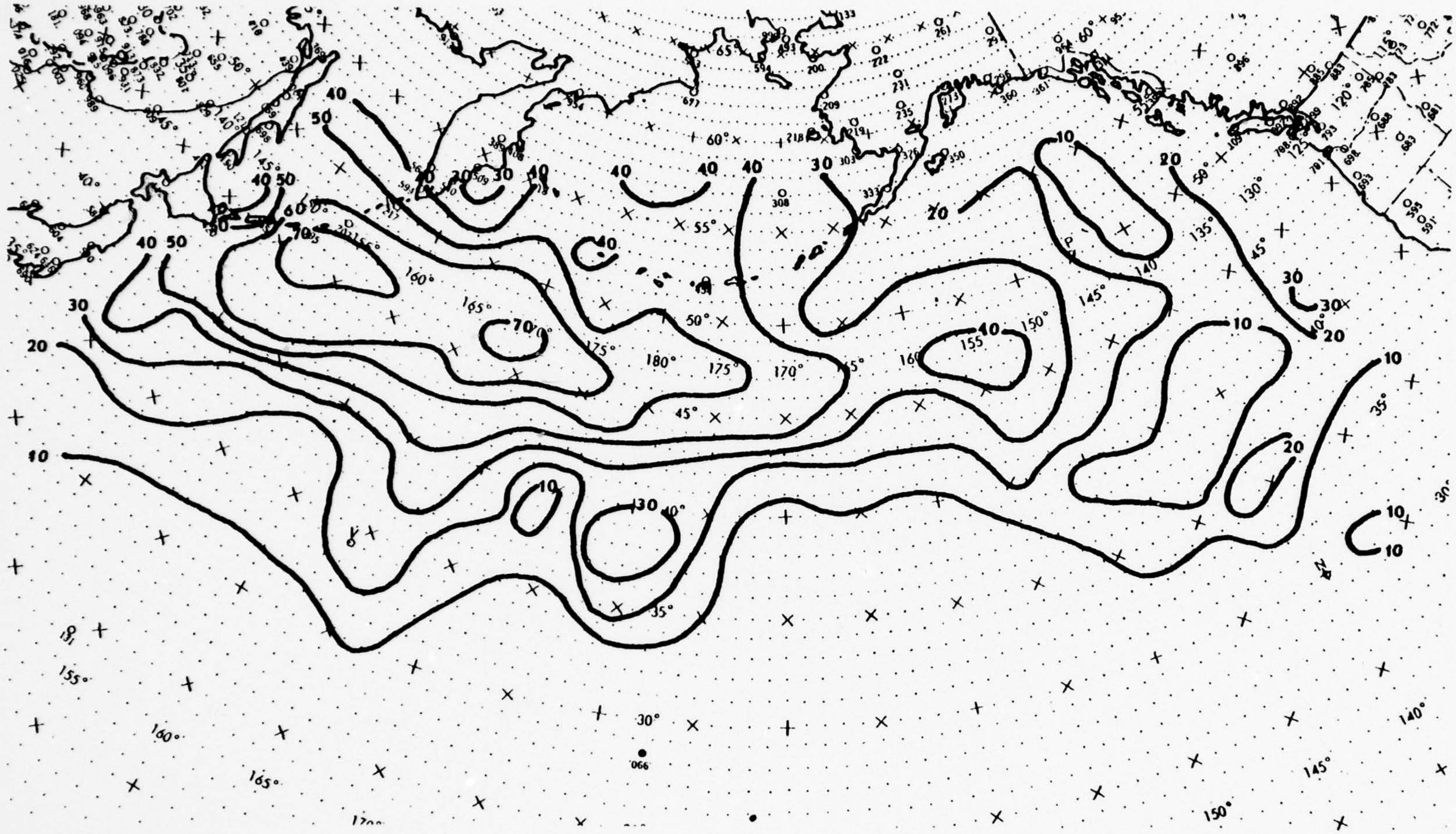

Figure 13. Analysis of Fog Score grid point data [from regression equation (9)] (per cent) for 0000 GMT, 24 July 1976.

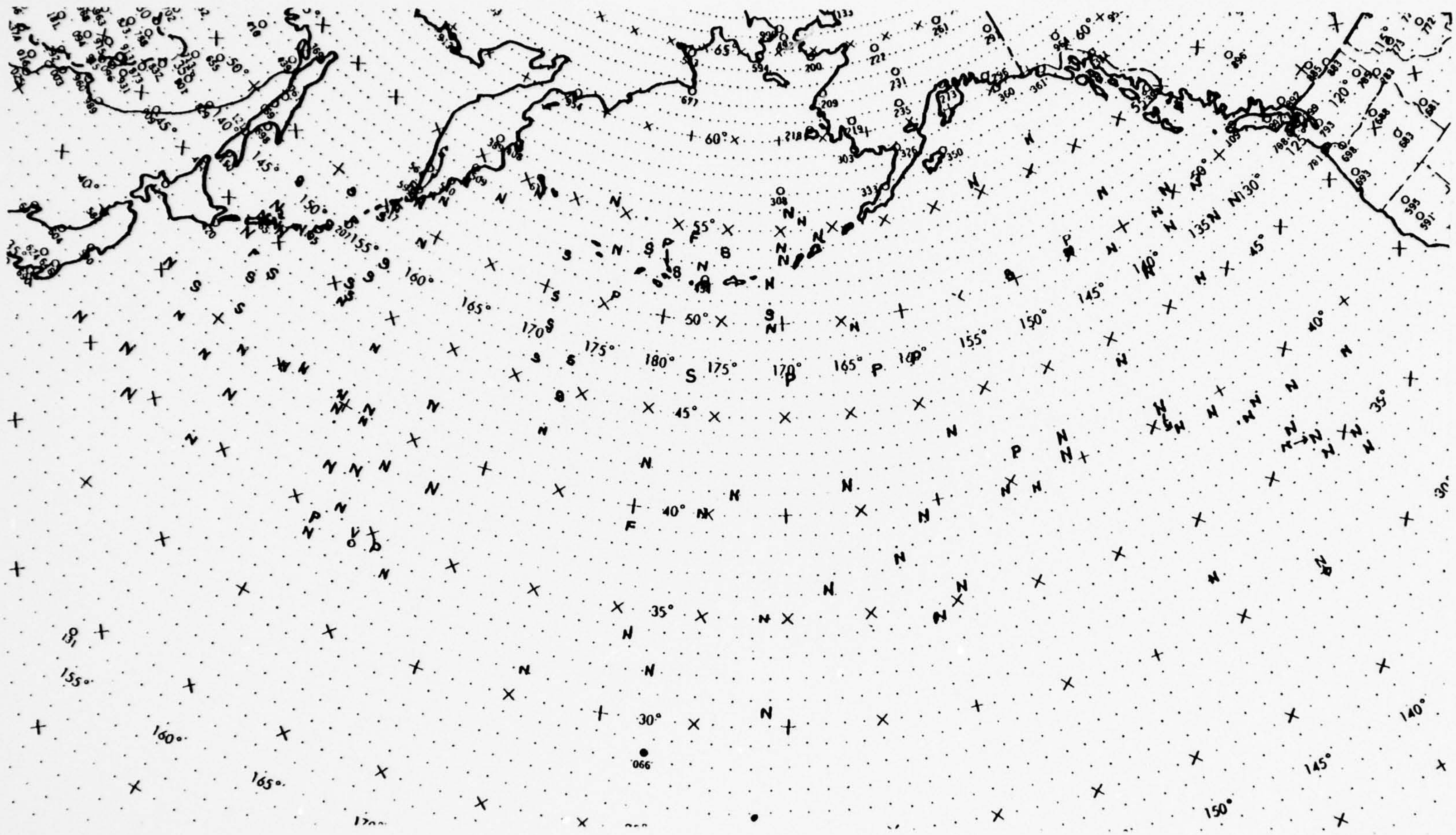

Figure 14. Categorized synoptic observations (FOGCAT) for 0000 GMT, 24 July 1976. S = Strong Foggers, F = Foggers, P = Past/Weak Foggers, M = Maybe Foggers, N = Non-Foggers.

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